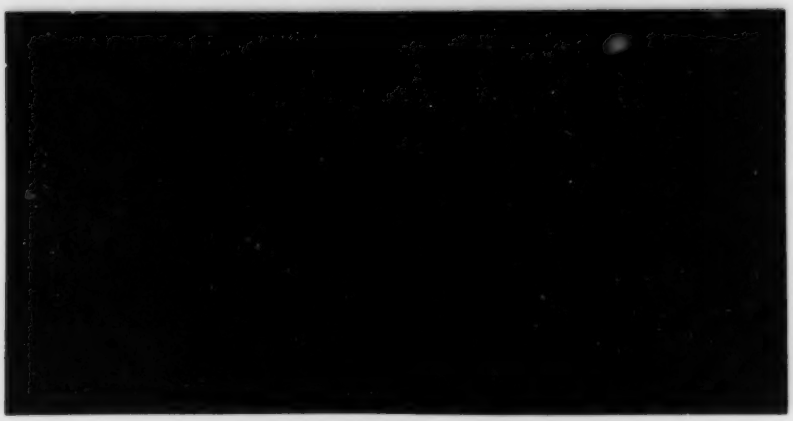
# REPORT 18



SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMÉLIORATION

DU MILIEU PÉDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

**SWEEP**

*is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.*

## PURPOSES

*There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.*

## BACKGROUND

*The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.*

**PAMPA**

*est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.*

## SES BUTS

*Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.*

## SES GRANDES LIGNES

*L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.*

100-05253/

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

# EFFECTS OF MANAGEMENT ON SOIL HYDRAULIC PROPERTIES:

## FINAL REPORT

September, 1990


| | |
|---|---|
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## EXECUTIVE SUMMARY

A new and particularly useful field instrument, the Guelph Pressure Infiltrometer has been developed for determining insitu measurements of soil hydraulic properties. The objectives of this study were to assess the effects of management on changes in surface hydraulic properties. Specific objectives were:

1. To further test the relationship between rainfall runoff (from rainfall simulation experiments) and predicted runoff using measurements of $K_{fs}$, $\phi_m$, $\Delta\theta$, and Tp from the pressure infiltrometer.

2. To examine the temporal changes in hydraulic properties measured with the pressure infiltrometer under two tillage systems and compare them to temporal changes in surface runoff (simulated).

3. To examine the effects of different cropping/tillage systems on changes in surface hydraulic properties.

Measurements were taken on 5 Tillage-2000 sites and also at the Elora Research Station, Univ. of Guelph. At the field scale sites, paired benchmarks were selected to cover the major soil and topographic changes in the field. A pressure infiltrometer attachment for the Guelph permeameter was used to obtain measurements of field saturated hydraulic conductivity $K_{fs}$ and matric flux potential $\phi_m$ on each of the tillage/soil landscape combinations. Undisturbed soil cores were taken to determine bulk density, total porosity, saturated hydraulic conductivity, moisture retention curves, and an estimate of macro-porosity.

At three of the T2000 sites rainfall simulation studies were also carried out as part of a Ministry of Environment project. The rainfall simulation trials gave steady runoff, infiltration rates, and soil loss rates to compare to the pressure infiltrometer and undistrubed core measurements. Detailed measurements at three times during the year were taken at one of the sites (D. Lobb's).

The detailed measurements at D. Lobb's site indicated that no-tillage (9 yrs) resulted in;

1. higher bulk density
2. lower total porosity
3. lower macro-porosity
4. lower saturated hydraulic conductivity

5. lower field saturated hydraulic conductivity
6. lower matric flux potential
7. shorter times to ponding and runoff, and
8. lower infiltration rates (higher runoff)

compared to a moldboard treatment. The results were consistent across all measurement times. Similar effects of no-tillage compared to a minimum tillage treatment were also observed at a second site. No significant differences between no-till and other tillage systems were found at the remaining sites. Comparisons of minimum tillage and moldboard tillage treatments also indicated no influence of tillage on surface hydraulic properties.

At every site where both rainfall simulation and Guelph pressure infiltrometer measurements were taken, the data from both methods were comparable. Thus, the pressure infiltrometer should be a reliable, cost effective instrument for evaluating management effects on hydraulic properties. The portability and minimum site disturbance of the permeameter make it a good choice for small plot experiments.

The data suggest that there is a risk of increased surface runoff on no-tillage plots. The main factors resulting in decreased soil loss in no-till appear to be increased surface protection and decreased particle detachment, not decreased runoff. The risk of increased surface water runoff may be significant for the movement of non-adsorbed chemicals or soil additions (such as manure).

The increased runoff and decreased infiltration rates in the no-till does not support the hypothesis that no-till increases the risk of movement of chemicals to the groundwater.

TABLE OF CONTENTS


| | PAGE |
|---|---|
| Executive Summary | i |
| Table of Contents | iii |
| List of Tables | vi |
| List of Figures | xi |
| Glossary of Terms | xii |
| 1.0 Introduction | 1 |
| 1.1 Background | 1 |
| 1.2 Conclusions from 1988 TED study | 2 |
| 1.3 Objectives | 4 |
| 2.0 Theory | 5 |
| 2.1 Pressure Infiltrometer | 12 |
| 2.2 Tension Infiltrometer | 14 |
| 2.3 Instrument Availability | 16 |
| 3.0 Materials and Methods | 17 |
| 3.1 Site Selection and Characterization | 17 |
| 3.2 Methods | 17 |
| 4.0 Results and Discussion for 1989 Field Season | 21 |
| 4.1 Temporal Changes in Surface Hydraulic Properties | 21 |
| 4.1.1 Site Description - D. Lobb T-2000 Site Clinton, Ontario | 21 |
| 4.1.2 Results and Discussion - April Sampling Period | 23 |
| 4.1.3 Results and Discussion - June Sampling Period | 46 |
| 4.1.4 Summary of Measurements at D. Lobb's | 52 |
| 4.2 Surface Hydraulic Properties | 58 |
| 4.2.1 Site Description - D. Ghent T-2000 Site, Mt. Forest, Ontario | 58 |
| 4.2.2 Results and Discussion | 58 |
| 4.2.3 Site Description - F. Anthony T-2000 Site, Halton Hills, Ontario | 68 |
| 4.2.4 Results and Discussion | 68 |
| 5.0 Study Sites With Only An Assessment of Surface Properties | 81 |
| 5.1 Elora Research Station | 81 |
| 5.1.1 Site Description | 81 |
| 5.1.2 Results and Discussion | 81 |
| 5.2 A. Jones T-2000 Site, Fingal Ontario | 90 |
| 5.2.1 Site Description | 90 |

5.2.2 Results and Discussion..... 90
5.2.3 Site Description - P. Johnson T-2000 Site, Guelph, Ontario ..... 99
5.2.4 Results and Discussion..... 99

6.0 Summary ..... 108

7.0 Acknowledgements..... 110

8.0 Literature Cited ..... 111

Appendices

APPENDICES

Volume 2 - Appendices I - IV


| | | Page |
|---|---|---|
| Appendix I | Ponded infiltration from a single ring: I. Analysis of Steady Flow ..... | 117 |
| Appendix II | Raw Field Data for D. Lobb T-2000 site 1989..... | 166 |
| | a. Guelph Pressure Infiltrometer Data for Permanent Runoff Plots - Clinton, Ontario, April 1989..... | 167 |
| | b. Guelph Pressure Infiltrometer Data for 1m x 1m plots - Clinton, Ontario, April 1989..... | 186 |
| | c. Pores Size Distribution and Soil Water Retention Curve Data - Permanent Plots, April 1989..... | 196 |
| | d. Pore Size Distribution and Soil Water Retention Curve Data - 1m x 1m plots, April 1989..... | 215 |
| | e. Guelph Pressure Infiltrometer Data - Clinton, Ontario, June 1989..... | 225 |
| Appendix III | a. Guelph Pressure Infiltromter Data for D. Ghent T-2000 Site, Mt. Forest, Ontario, 1989..... | 245 |
| | b. Pore Size Distribution and Soil Water Retention Curve Data for D. Ghent T-2000 Site, 1989..... | 257 |
| Appendix IV | a. Guelph Pressure Infiltrometer Data for F. Anthony T-2000 Site, Halton Hills, Ontario 1989..... | 267 |
| | b. Pore Size Distribution and Soil Water Retention Curve Data for F. Anthony T-2000 Site, 1989..... | 284 |


Volume 3 Appendices V - VII


| | | |
|---|---|---|
| Appendix V | a. Guelph Pressure Infiltrometer Data from Elora Research Station, 1989..... | 302 |
| | b. Pore Size Distribution and Soil Water Retention Curve Data for Elora Research Station, 1989..... | 324 |
| Appendix VI | a. Guelph Pressure Infiltrometer Data for A. Jones T-2000 Site, Fingal, Ontario..... | 344 |
| | b. Pore Size Distribution and Soil Water Retention Curve Data for A. Jones T-2000 Site, 1989..... | 356 |
| Appendix VII | a. Guelph Pressure Infiltrometer Data for P. Johnson T-2000 Site, Guelph, Ontario, 1989..... | 367 |
| | b. Pore Size Distribution and Soil Water Retention Curve Data for P. Johnson T-2000 Site, 1989..... | 389 |

## LIST OF TABLES


| | | Page |
|---|---|---|
| Table 1. | Description of 1989 field sites sampled for hydraulic properties and rainfall simulation ..... | 18 |
| Table 2. | Description of 1989 field sites sampled for characterization of hydraulic properties only ..... | 18 |
| Table 3. | Summary of $K_{fs}$ from pressure infiltration April 1989 - D. Lobb (permanent plots) ..... | 24 |
| Table 4. | Comparison of $K_{fs}$ from pressure infiltrometer and $K_{sat}$ from undisturbed cores at Clinton, Ontario, April 1989 (permanent plots) ..... | 26 |
| Table 5. | Summary of $K_{fs}$ for 1m x 1m plots at D. Lobb - April 1989 ..... | 27 |
| Table 6. | Comparison of $K_{fs}$ from pressure infiltration and $K_{sat}$ from undisturbed cores at D. Lobb (April 1989) for 1m x 1m plots ..... | 28 |
| Table 7. | Overall average of $K_{fs}$ for moldboard plough versus no-till by slope position at D. Lobb - April 1989 ..... | 30 |
| Table 8. | Measured data for calculation of predicted time to ponding Tp for D. Lobb (permanent plots) April 1989 Hill 1 ..... | 31 |
| Table 9. | Measured data for calculation of predicted time to ponding Tp for D. Lobb (permanent plots) April 1989 Hill 2 ..... | 33 |
| Table 10. | Comparison of predicted time to ponding Tp for tillage treatments at D. Lobb, April 1989 (permanent plots) ..... | 33 |
| Table 11. | Measured data for calculation of predicted time to ponding Tp for D. Lobb (1m x 1m plots) - April 1989 ..... | 34 |
| Table 12. | Comparison of predicted time to ponding for tillage treatments at D. Lobb (1m x 1m plots) - April, 1989 ..... | 35 |
| Table 13. | Comparison of overall average predicted time to ponding for April sampling period (D. Lobb)..... | 37 |
| Table 14. | Runoff characteristics of Lobb simulation (2.8 $mm \cdot min^{-1}$) in April, 1989 ..... | 38 |

PAGE

Table 15. Comparison of measured time to runoff $T_R$ and predicted time to ponding Tp ..... 40

Table 16. Comparison of $K_{fs}$ and $K_{sat}$ for overall average at D. Lobb April, 1989 ..... 41

Table 17. Summary of tillage effect on average matric flux potential $\phi m$ measurements for D. Lobb, April 1989 (permanent plots) ..... 41

Table 18. Summary of tillage effects on average matric flux potential $\phi_m$ for D. Lobb (1m x 1m plots) - April, 1989 ..... 42

Table 19. Summary of tillage effects on overall average matric flux potential $\phi_m$ for D. Lobb, April 1989 sampling period ..... 42

Table 20. Measured porosity indices from undisturbed cores for D. Lobb, April 1989 (permanent plots) ..... 43

Table 21. Measured porosity indices from undisturbed cores for D. Lobb, April 1989 (1m x 1m plots)..... 44

Table 22. Summary of average treatment effects on porosity indices from all cores sampled at D. Lobb, April 1989..... 45

Table 23. Summary of saturated hydraulic conductivity from the GPI for D. Lobb, June 1989 ..... 47

Table 24. Measured data for calculation of predicted time to ponding Tp for D. Lobb, June 1989 (Hill 1) ..... 48

Table 25. Measured data for calculation of predicted Tp for D. Lobb, June 1989 (Hill 2) ..... 49

Table 26. Comparison of average predicted Tp for tillage treatments at D. Lobb for June 1989 sampling period ..... 49

Table 27. Summary of tillage effects on average matric flux potential measurements at D. Lobb for June sampling period. 50

Table 28. Runoff characteristics from D. Lobb rainfall simulation in June 1989 for large plots ..... 51

Table 29. Comparison of average $K_{fs}$ from the GPI for D. Lobb 1988-89 ..... 53

PAGE

Table 30. Comparison of tillage effects on average matric flux potential at D. Lobb for three sampling periods 1988-89 ..... 54

Table 31. Comparison of tillage effects on average predicted time ponding for D. Lobb 1988-89 ..... 55

Table 32. Comparison of average porosity indices for three sampling periods at D. Lobb, 1988-89 ..... 56

Table 33. Summary of rainfall simulation data for D. Lobb 1988-89 ..... 57

Table 34. Measured $K_{fs}$ from pressure infiltrometer for D. Ghent (T-2000) ..... 61

Table 35. Summary of average $K_{fs}$ measured with the GPI (D. Ghent) ..... 61

Table 36. Comparison of $K_{fs}$ from the GPI and $K_{sat}$ from undisturbed cores (D. Ghent) ..... 63

Table 37. Runoff data from rainfall simulation trials at D. Ghent ..... 63

Table 38. Summary of tillage effects on average matric flux potential $\phi_m$ measurements at D. Ghent (T-2000) ..... 63

Table 39. Measured data for calculation of predicted time to ponding at D. Ghent ..... 64

Table 40. Comparison of predicted Tp for tillage treatments at D. Ghent ..... 65

Table 41. Summary of porosity indices from undisturbed cores for D. Ghent ..... 66

Table 42. Summary of average treatment effects in porosity indices from undisturbed cores for D. Ghent ..... 66

Table 43. Summary of measured $K_{fs}$ from the GPI for F. Anthony ..... 71

Table 44. Comparison of average $K_{fs}$ and $K_{sat}$ for F. Anthony ..... 72

Table 45. Runoff measurements on Anthony simulation in Sept., 1989.. 74

Table 46. Summary of tillage effects on average matric flux potential $\phi_m$ measurements for F. Anthony ..... 75

Table 47. Measured data for calculation of predicted Tp for F. Anthony ..... 76

PAGE

Table 48. Comparison of predicted Tp for tillage treatments at F. Anthony ..... 77

Table 49. Measured porosity indices from undisturbed cores for F. Anthony ..... 78

Table 50. Summary of average treatment effects on porosity indices for F. Anthony ..... 79

Table 51. Measured $K_{fs}$ from the GPI for Elora Research Station ..... 82

Table 52. Summary of average $K_{fs}$ for Elora Research Station ..... 84

Table 53. Comparison of average $K_{fs}$ and $K_{sat}$ for Elora Research Station ..... 84

Table 54. Summary of tillage effects on average matric flux potential measurements for Elora Research Station ..... 85

Table 55. Measured porosity indices for Elora from undisturbed cores - Block 1 ..... 86

Table 56. Measured porosity indices for Elora from undisturbed cores - Block 2 ..... 87

Table 57. Summary of porosity indices for Elora from undisturbed cores - Block 3 ..... 88

Table 58. Summary of average treatment effects on porosity indices for Elora Research Station ..... 89

Table 59. Summary of hydraulic properties from the GPI ($K_{fs}$) and undisturbed cores ($K_{sat}$) for A. Jones ..... 93

Table 60. Summary of $K_{fs}$ for A. Jones T-2000 site, Fungal, Ontario ..... 94

Table 61. Comparison of average $K_{fs}$ from the GPI and $K_{sat}$ from undisturbed cores for A. Jones ..... 96

Table 62. Summary of porosity indices from undisturbed cores (A. Jones T-2000) ..... 97

Table 63. Summary of average treatment effects on porosity indices from undisturbed cores - A. Jones T-2000 ..... 98

PAGE

Table 64. Measured $K_{fs}$ from the GPI for P. Johnson T-2000 ..... 102

Table 65. Comparison of $K_{fs}$ and $K_{sat}$ for P. Johnson T-2000 ..... 103

Table 66. Summary of tillage effects on average matric flux potential $\phi_m$ measurements (P. Johnson) ..... 105

Table 67. Calculated porosity indices from undisturbed core measurements (Johnson T-2000) ..... 106

Table 68. Summary of porosity indices from undisturbed cores for P. Johnson T-2000..... 107

# LIST OF FIGURES


| | | PAGE |
|---|---|---|
| Fig. 1. | Typical values for micro-hydrological properties in three arbitrarily chosen soils ..... | 7 |
| Fig. 2. | Field techniques for measuring the hydraulic conductivity of soils ..... | 8 |
| Fig. 3. | An idealized relationship between hydraulic conductivity and soil water potential ..... | 9 |
| Fig. 4 | Farm and study site location for D. Lobb T-2000 site Clinton, Ontario ..... | 22 |
| Fig. 5. | Site location - D. Ghent T-2000 site, Mt. Forest, Ontario ..... | 59 |
| Fig. 6. | Detailed plot layout - D. Ghent T-2000 site ..... | 60 |
| Fig. 7. | Site location - F. Anthony T-2000 site, Halton Hills, Ontario ..... | 69 |
| Fig. 8. | Detailed plot layout - F. Anthony T-2000 site ..... | 70 |
| Fig. 9. | Site location - A. Jones T-2000 site, Fingal, Ontario ..... | 91 |
| Fig. 10. | Detailed plot layout - A. Jones T-2000 site ..... | 92 |
| Fig. 11. | Site location - P. Johnson T-2000 site, Guelph, Ontario ..... | 100 |
| Fig. 12. | Detailed plot layout - P. Johnson T-2000 site ..... | 101 |

## Glossary of Terms

GP - Guelph Permeameter - instrument used to determine saturated hydraulic parameters in a field soil (auger hole method). Calculations are based on the 3D solution of infiltration in an unsaturated soil.

GPI - Guelph Pressure Infiltrometer - attaches to the body of the GP and allows for surface measurement of soil hydraulic parameters.

GTI - Guelph Tension Infiltrometer - attaches to the body of the GP and a second Mariotte bottle to apply negative head for flow from a porous disk.

$K_{fs}$ - "field-saturated" hydraulic conductivity (units - $m \cdot s^{-1}$)

$\phi_m$ - matric flux potential or the unsaturated component of flow in soil (units - $m^2 \cdot s^{-1}$)

Ksat - "saturated" hydraulic conductivity usually determined in a laboratory from an intact soil core or one artificially packed to a known bulk density.

$\alpha$ - alpha parameter calculated from the ratio $K_{fs}/\phi_m$ (units - $m^{-1}$)

$\theta_v$ - volumetric moisture content measured with a Tectronix 1502B cable tester (e.g units - 4.3% - 0.043 $m^3 \cdot m^{-3}$).

Tp - estimated time to ponding calculated from soil parameters measured with the GPI.

Total Porosity - total volume of pore space expressed as a percentage of the total volume of soil.

Macroporosity - large soil pores, corresponding to pore size >0.12 mm diameter, which drain when put under pressure 0-25 mb.

Bulk Density - ($\rho_b$) mass of soil per volume of soil (units $g \cdot cm^{-3}$)

# 1.0 INTRODUCTION

## 1.1 Background

The trend during the past several decades in soil physics has been towards field experimentation. Many of the principles of water and solute transport had been thoroughly tested in the laboratory during the previous decades, primarily using air-dried, sieved soil. At times, "undisturbed" soil cores were used. However, applying these laboratory determined hydraulic and solute transport parameters to field situations often underestimated the travel times of water and solutes to various depths (and ultimately to groundwater). What once was perceived to be one dimensional flow appeared to actually be a complex two (or three) dimensional flow under field conditions. Macropores, consisting of cracks, fractures, decayed root passageways, wormholes, etc., can lead to preferential vertical flow, particularly under conditions of surface ponding. Fingering effects, brought about by textural/structural discontinuities, can also lead to two or three dimensional flow. What was once perceived to be rather straightforward, one dimensional flow has turned out to be much more complex in nature.

A new and particularly useful field instrument, the Guelph Pressure Infiltrometer (GPI), provides a technique for determining valid in-situ measurements of soil hydraulic properties such as saturated hydraulic conductivity and matrix flux potential. The GPI has advantages over the more labour intensive laboratory techniques since it provides data that is more pertinent to the field situation, allowing immediate on-site estimates while the investigators are still at the study area. A detailed discussion and field testing of the GPI has been given in a previous TED research report (Kachanoski et al. 1989) and serves as an appendix to this report. Briefly the study had the following conclusions and recommendations.

## 1.2 Conclusions From 1988 TED Study

The pressure infiltrometer is a fast, reliable method for estimating surface field saturated hydraulic conductivity $K_{fs}$. The $K_{fs}$ values correlated significantly with the more labour intensive, slower, undisturbed core laboratory method for measurement of saturated hydraulic conductivity Ksat ($r = 0.92$). The pressure infiltrometer can also be used to estimate the unsaturated flow component, the Matric Flux Potential $\phi_m$, and subsequently an estimate of the effective time to ponding (Tp) for a given rainfall rate. An estimate of the average flow weighted capillary length scale can also be obtained. The predicted effective time to ponding Tp was significantly correlated ($r = 0.88$) to measured surface runoff from rainfall simulation studies. The regression relationship was almost identical to the theoretical equation for predicted runoff potential. The error in predicted runoff was negligible in the no-till treatment (1.65 cm predicted vs. 1.73 cm measured) but significant in the moldboard treatment on two out of four sites where substantial erosion occurred.

Matric Flux Potential $\phi_m$ measurements from the pressure infiltrometer were significantly lower in the 8 year no-till compared to the 1 year no-till, at similar initial soil water contents suggesting a decrease in macroporosity in the 8 year no-till. Soil core measurements substantiated the $\phi_m$ measurement indicating a significant decrease in total porosity in the 8 year no-till. In nearly all cases this decrease in total porosity for the 8 year no-till, as compared to the moldboard and 1 year no-till, was explained by a decrease in macroporosity (pore sizes greater than 0.12mm in diameter). This decrease in macroporosity was the cause of the significant decrease in field saturated hydraulic conductivity $K_{fs}$ in the 8 year no-till, measured with the pressure infiltrometer. On average $K_{fs}$ in the 8 year

no-till plots was 7x lower than the moldboard treatment and 4x lower than the 1 year no-till. This provides direct evidence of the degree of consolidation occurring over time after tillage.

The pressure infiltrometer has proven to be a reliable instrument for providing useful information on saturated and unsaturated flow, and can be used to estimate the effective time to ponding Tp, which appears to be a useful parameter for assessing management effects on potential runoff generation. A combination of the $K_{fs}$, $\phi_m$, $\Delta\theta$ and calculated Tp, along with the stability index $f_s$ would provide you with an extremely useful set of information for assessing the effects of management on surface hydraulic properties. More data is needed, however, to confirm the relationship between effective time to ponding Tp and runoff.

The macroporosity estimates from the surface cores were very useful in validating the cause of the decreased $K_{fs}$ in the no-till. However, a measurement of total porosity, which could be estimated from bulk density, along with a measurement of $K_{fs}$ from the pressure infiltrometer would give approximately the same conclusion since $K_{fs}$ is sensitive to macropores. The estimate of macroporosity using pressure plate apparatus and undisturbed cores is expensive and very time consuming. For monitoring purposes an estimate of bulk density (fast and simple) coupled with measurements from the pressure infiltrometer may be sufficient.

## 1.3 Objectives

The general objective of the 1989-1990 study was to use the pressure infiltrometer to assess the effects of management on surface hydraulic properties. Specific objectives were:

1. To further test the relationship between rainfall runoff (from rainfall simulation experiments) and predicted runoff using measurements of $K_{fs}$, $\phi_m$, $\Delta\theta$, and Tp from the pressure infiltrometer.
2. To examine the temporal changes in hydraulic properties measured with the pressure infiltrometer under two tillage systems and compare them to temporal changes in surface runoff (simulated).
3. To examine the effects of different cropping/tillage systems on changes in surface hydraulic properties.

## 2.0 THEORY

A detailed summary of the theory and methodology of using the surface pressure and tension infiltrometers has been presented in the previous TED report (Kachanoski et al. 1989), which is in turn a summary of Reynolds and Elrick (1990). This section is included to review the existing body of knowledge and to include any recent additions to the theory.

The flux of water in soils is well described by the relationship generally attributed to Darcy (1856) and later extended to unsaturated soil by Buckingham (1907):

$$J_w = - K(\psi)\nabla\psi_h \qquad (1)$$

where $J_w$ ($LT^{-1}$) is the volume flux density of water, $K$ ($LT^{-1}$) is the hydraulic conductivity and is a function of the soil water potential $\psi$ (L), and $\psi^h$ (L) is the hydraulic head. L and T stand for the dimensions of length and time respectively. The relationship between the potentials is given by

$$\psi_h = \psi + \psi_z \qquad (2)$$

where $\psi_z$ (L) is the gravitational potential. If the vertical coordinate z is defined to be positive upwards, then Eq. (1), for one dimensional flow, can be written as

$$J_w = -K(\psi)\partial\psi_h/\partial z = -K(\psi)\partial\psi/\partial z - K(\psi) = -D(\theta)\partial\theta/\partial z - K(\theta) \qquad (3)$$

In Eq. (3) we have made use of the relationship between water content, $\theta$ ($L^3L^{-3}$), and the water potential, $\psi$ and have also introduced the soil water diffusivity, D ($L^2T^{-1}$) where

$$D = K(\psi)\ \partial\psi/\partial\theta \qquad (4)$$

Note that the use of $D(\theta)$ limits the application of the diffusivity form to unsaturated soil only as $D(\theta)$ becomes undefined as the water content approaches saturation. There is no such restriction on the use of $K(\theta)$ ( or $K(\psi)$).

Some typical values for these micro-hydrological parameters are given in Fig. 1. The empirical relationships between the water content and water potential for three arbitrarily chosen soils are given in Fig. 1a and shown graphically in Fig. 1b. The relationship between hydraulic conductivity and water potential for the three soils is shown in Fig. 1c and was assumed to have the useful empirical form (Gardner, 1958):

$$K(\psi) = K_{fs} e^{\alpha\psi} \; ; \; \psi \leq 0 \qquad (5)$$

where $\alpha$ is the slope of ln K vs $\psi$. For plain field sand, Guelph loam and Yolo clay, $K_{fs}$ and $\alpha$ were assigned values of $3.44 \times 10^{-5}$ $m \cdot s^{-1}$, $3.67 \times 10^{-6}$ $m \cdot s^{-1}$, $1.23 \times 10^{-7}$ $m \cdot s^{-1}$ and 13.06, 3.36 and 1.88 respectively. The $D(\theta)$ relationship shown in Fig. 1d was obtained from Eq. 4. These values are typical of air-dried, sieved and repacked soils as determined from laboratory studies. We show later that these micro-hydrological characteristics can be somewhat different under field conditions where macropores may be present and where the flow boundary conditions are considerably different from that of a laboratory core. Unfortunately, good field data is generally not available primarily because of the lack of a good methodology.

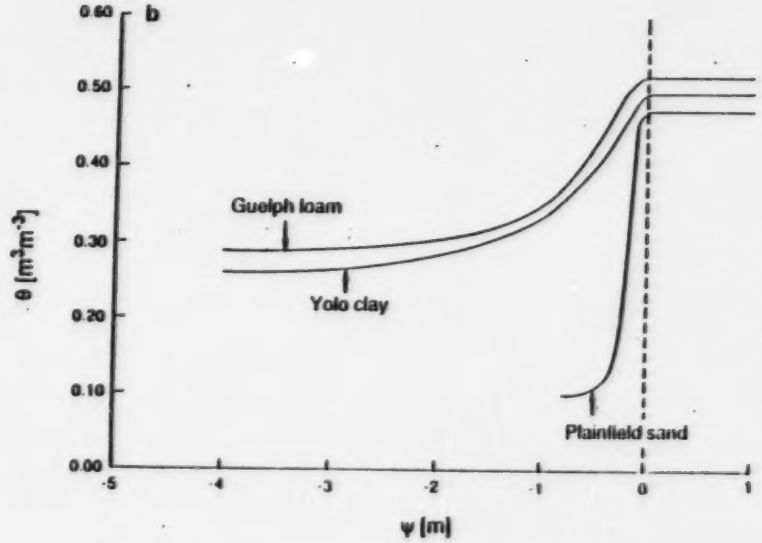
As shown in Eq. (1) and (3), the volume flux density of water is given by the product of the soil hydraulic property (hydraulic conductivity or soil water diffusivity) and the appropriate gradient(s). The hydraulic properties applicable to flow from an auger hole in which ponded water is present (Fig. 2a) and from a pressure infiltrometer (Fig. 2b) in which water is supplied to the surface at a positive pressure involve both the saturated and unsaturated components of the hydraulic conductivity (Fig. 2 and 3). In Fig. 2, the extent of the saturated bulbs and the position of the wetting fronts are shown for some arbitrary times which are sufficiently large that

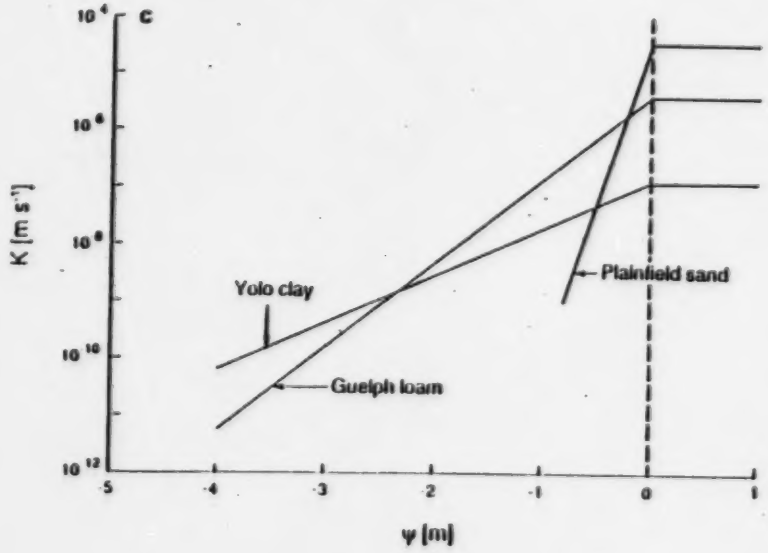
a

| | $P_1$ ($cm^3cm^{-3}$) | $P_2$ ($cm^3$) | $P_3$ | $P_4$ ($cm^3cm^{-3}$) |
|---|---|---|---|---|
| Plainfield | 0.377 | $1.54 \times 10^5$ | 4.0 | 0.1 |
| Guelph | 0.243 | $4.21 \times 10^3$ | 2.0 | 0.28 |
| Yolo | 0.259 | $6.09 \times 10^2$ | 1.5 | 0.24 |

$$\theta(\psi) = \frac{P_1 P_2}{P_2 + |\psi|^{P_3}} + P_4$$

where $\psi$ is in cm and $\theta$ is in $cm^3cm^{-3}$



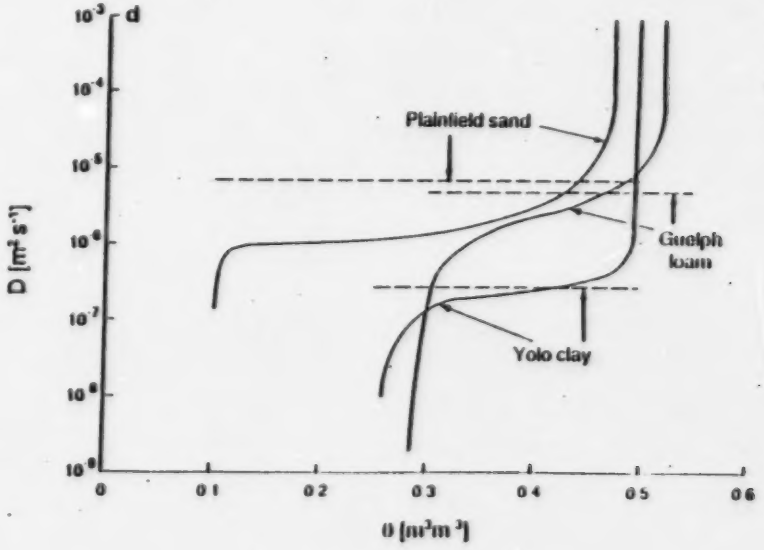




Figure 1: Typical values for the microhydrological parameters for three arbitrarily chosen soils: (a) the soil parameters; (b) the water content-water potential relationships; (c) the hydraulic conductivity-water potential relationships; and (d) the soil water diffusivity-water content relationships.

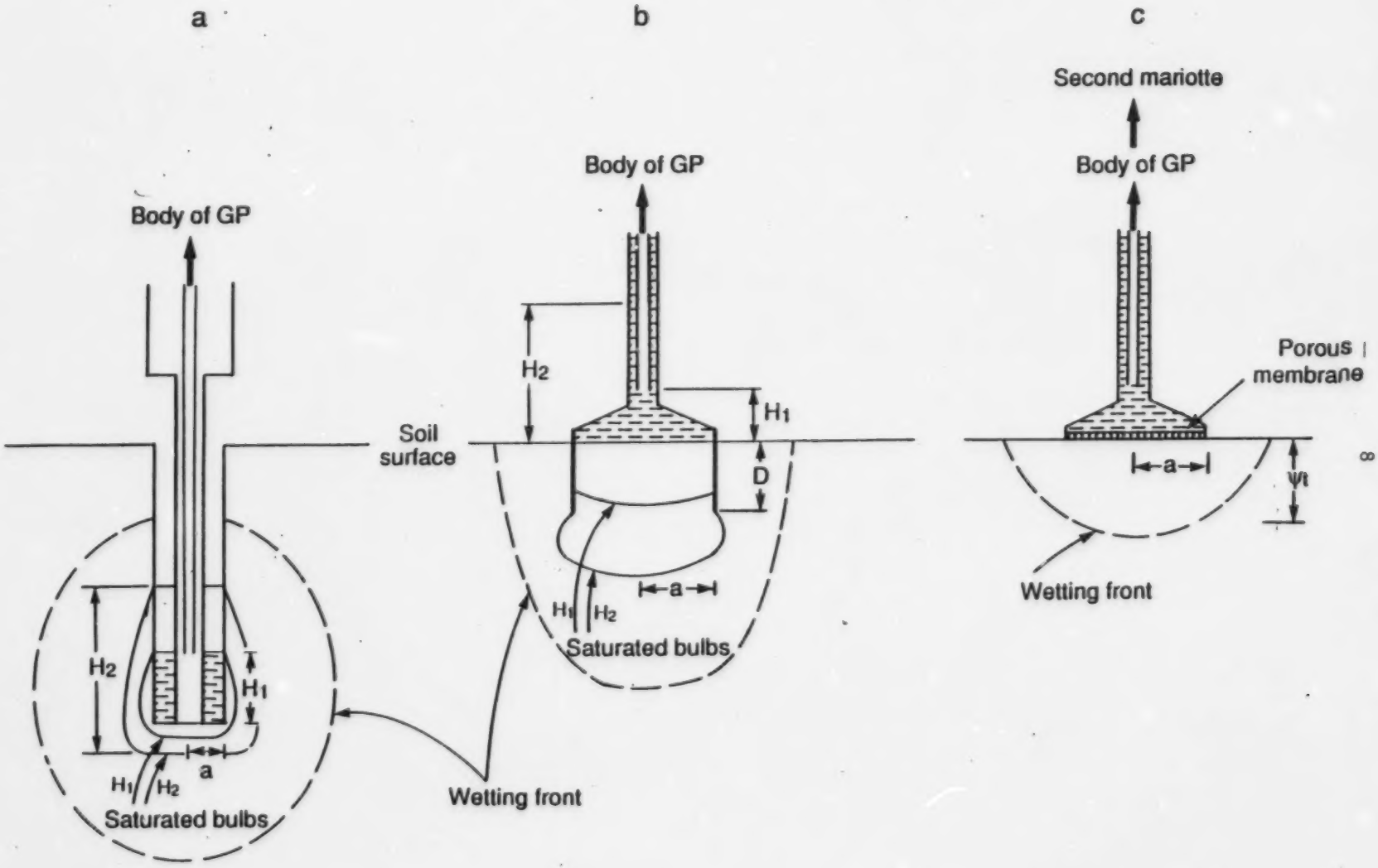



FIGURE 2 Field techniques for measuring the hydraulic conductivity of soils: (a) the Guelph Permeameter (b) the Guelph Pressure Infiltrometer and (c) the tension infiltrometer. In (a) and (b) the approximate positions of the steady state saturated bulbs for two ponded heights, $H_1$ and $H_2$, are shown. No saturated bulb develops under the tension infiltrometer.

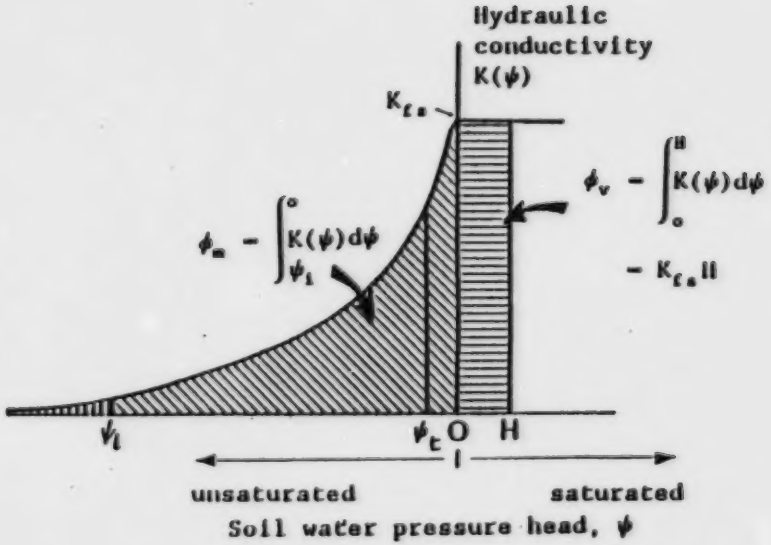



Figure 3: An idealized relationship between hyraulic conductivity and soil water potential.

steady flow has essentially been established at the two heights. At true steady state, which occurs as time approaches infinity, the wetting front would theoretically extent to infinity (or to boundaries established for a numerical solution). At true steady state, the size of the saturated bulb remains finite and essentially the same as those depicted in Fig. 2a and 2b. There is no saturated bulb under the tension infiltrometer (Fig. 2c).

The relationship between hydraulic conductivity, K and water potential $\psi$ is shown in Fig. 3. In our approximate analytical analysis, it is the integral properties of the $K(\psi)$ relationship that we show later to be of importance. We define the driving flux potential, $\phi_d$, as follows:

$$\phi_d = {}_{\psi i}\int^{\psi} K(\psi)d\psi = {}_{\psi i}\int^{0} K(\psi)d\psi + {}_{0}\int^{\psi} K(\psi)d\psi = \phi_m + \phi_v \qquad (6)$$

where $\psi$ (L) is the soil water pressure head. The matric flux potential, $\phi_m$, is defined as

$$\phi_m = {}_{\psi i}\int^{0} K(\psi)d\psi \qquad (7)$$

and $\phi_v$, the velocity (flux) potential (Kirkham and Powers, 1972) is defined as

$$\phi_v = {}_{0}\int^{\psi} K(\psi)d\psi = K_{fs} \cdot H \qquad (8)$$

In a soil in which the initial or background soil water pressure head is $\psi_i$, corresponding to an initial water content $\theta_i$, the driving flux potential is given by $\phi_d = \phi_m + \phi_v$ (the sum of the areas shown in Fig. 3) and is the value of $\phi_d$ at the bottom surface of the test well. Note that the $\alpha$ parameter ($0 < \alpha < \infty$) of Eq. (5) is the slope of ln K vs $\psi$. We may set

$$\lambda_c = \alpha^{-1} \qquad (9)$$

where $\alpha$ is called the sorptive number and $\lambda_c$ the macroscopic capillary (or sorptive) length scale (White and Perroux, 1987).

Substituting (5) into (7) gives

$$\alpha = (K_{fs} - K_i)/\phi_m \qquad (10)$$

For this analysis we are more interested in $\alpha^*$, the ratio of $K_{fs}$ to $\phi_m$, where

$$\alpha^* = K_{fs}/\phi_m = \alpha/(1-K_i/K_{fs}) \qquad (11)$$

Thus the relationship between $\alpha^*$ and $\alpha$ depends upon $\psi_i$. For all soils when $\psi_i$ is at or below the field capacity value (i.e at the field capacity water content or drier) then $K_i \ll K_{fs}$ and $\alpha^* = \alpha$. However, in soils where $\psi_i$ approaches zero (soils very close to saturation), which can occur in very wet and in poorly drained soils, then $\alpha^*$ can be larger than $\alpha$.

It should be noted that $\alpha^*$ can also be interpreted as the suction at the wetting front of the Green-Ampt model:

$$|\psi_f| = 1/\alpha^* \qquad (12)$$

where $\psi_f$ is the wetting front potential (Mein and Farrell, 1974).

The steady state flow of water from the pressure infiltrometer can be approximated by equations of the form (Reynolds et al., 1985; Philip, 1985; Reynolds and Elrick, 1990):

$$Q = f(h,a)K_{fs} + g(H,a)\phi_m \qquad (13)$$

where $Q$ $(L^3T^{-1})$ is the <u>steady</u> intake rate of water, H (L) is the constant height of ponded water, a (L) is the radius of the well or infiltrometer, $K_{fs}$ $(LT^{-1})$ is the field saturated hydraulic conductivity and $\phi_m$ $(L^2T^{-1})$ is the matric flux potential. Note that it is the integral properties of the $K(\psi)$ relationship that are of importance when determining the steady state flow. From Fig. 3 it is shown that $\phi_m$ and $\phi_v$ represent the unsaturated and saturated areas under the $K(\psi)$ curve; however, it is easy to obtain $K_{fs}$ directly from $\phi_v$ because the rectangular area is given by $K_{fs} \cdot H$ and H is known. Thus the important integral properties are $K_{fs}$, $\phi_m$ and their ratio $\alpha^*$.

## 2.1 Pressure Infiltrometer

The most recent theory on the pressure infiltrometer has recently been accepted for publication and a copy of the final manuscript can be seen in Appendix 1 (Reynolds and Elrick, 1990). A brief outline of the theory is outlined here.

The Guelph Permeameter (GP) is a useful, field portable instrument that can provide valid in-situ measurements of soil hydraulic properties such as saturated hydraulic conductivity and matric flux potential. The method is simply a constant-head well technique with the GP apparatus being an in-hole Mariotte bottle (Fig. 2a). Calculations of $K_{fs}$ and $\phi_m$ are based on a steady state three dimensional solution of infiltration from a well into unsaturated soil (Baumgartner et al., 1987).

More recent advances in the theory have led to the development of the pressure infiltrometer which is designed specifically to measure $K_{fs}$ and $\phi_m$ at the soil surface, with minimal disturbance to the soil surface itself. A schematic diagram of the pressure infiltrometer is shown in Fig. 2b. In practice, a 10 cm diameter sealed ring is driven a known distance into the soil (from 1 to 5 cm depending on the soil properties) and a constant head (from 3 to 25 cm) is applied. Flow measurements are then taken until near steady state is obtained. Within limitations, the soil surface need not be disturbed and measurements can be taken on a grass or stubble surface.

The approximate analytical solution describing the flow process is given by (Reynolds and Elrick, 1990):

$$Q = (aH/G + \pi a^2)K_{fs} + (a/G)\phi_m \qquad (14)$$

$$= (aK_{fs}/G)H + \pi a^2 K_{fs} + a\phi_m/G \qquad (15)$$

where G is a dimensionless shape parameter and is determined from numerical solutions of the Richards equation.

Although not particularly obvious, the pressure infiltrometer approach has a number of advantages over that of the constant head well-permeameter (subsurface Guelph permeameter). If a two head technique is used, then the volume of soil occupied by the saturated bulb at the second height is simply the volume occupied by the saturated bulb at the first height plus the expanded portion at the bottom of the first bulb. At the second height the water must first flow through the saturated bulb that developed at the first ponded height and thus the effect of soil heterogeneity in the two volumes is minimized. The situation is complicated in that the wetted but unsaturated soil volumes of the wetting front also influence the steady flow rates. By comparison, the saturated bulb developed at the second ponded height in the constant head well permeameter includes new soil above the $H_1$ level which is in contact with the wetted surface of the well. Therefore, if the soil hydraulic properties are different in the enlarged saturated bulb (at the second ponded height) the effects of soil heterogeneity are maximized with regard to the steady flow obtained at the second ponded height. The effects of soil heterogeneity are important because the analysis assumes the soil properties to be homogeneous for both ponded height measurements.

From the theoretical point-of-view the pressure infiltrometer equation offers several advantages over the comparable equation for the constant head well permeameter. Most importantly, the coefficient G in Eq. (14) and (15) has been found to be essentially independent of H and the soil hydraulic properties (i.e. $K_{fs}$ and $\phi_m$) for a fixed radius a and depth of insertion, D. Therefore, if G can be taken to be constant then Eq. (15) gives a linear relationship between Q and H, with the slope determined for $K_{fs}$ only. This provides an excellent two height technique for determining $K_{fs}$ and if ($Q_2$-

$Q_1)/(H_2-H_1)$ is positive (which is realistic unless in the presence of an impeding layer for $Q_2$) then $K_{fs}$ must be positive. If $K_{fs}$ is determined from the slope, then $\phi_m$ can be determined from the Q intercept or from a given Q value, preferably $Q_2$. Preliminary measurements of Q vs. H, both from numerical simulations (based on the Richards equation) and from field tests, give a linear relationship between Q and H.

An alternative procedure is to use the one height approach and estimate $\alpha^*$. The appropriate equations for $K_{fs}$ and $\phi_m$ are therefore:

$$K_{fs} = GQ/(aH + \pi a^2 G + a/\alpha^*) \quad (16)$$

$$\phi_m = GQ/(aH + \pi a^2 G)\alpha^* + a \quad (17)$$

If desired, the pressure infiltrometer could be used for depth measurements by excavating a sufficiently large hole.

A 20 cm diameter pressure infiltrometer has been tested on very slowly permeable materials such as compacted earthen liners. Preliminary results indicate that hydraulic conductivities of the order of $10^{-9}$ $m \cdot s^{-1}$ can be measured using ponded heights up to 50 cm and an additional constant head burette system capable of measuring water volumes to 0.01 $cm^3$. For these slowly permeable soils measurements may take as long as one or several days before steady state flow is reached.

## 2.2 Tension Infiltrometer

The tension infiltrometer supplies water at a negative potential to the soil surface and thereby eliminates the effects of highly conducting macropores (if present) such as surface cracks, root passageways and worm channels. The instrument is useful for soil management studies where tillage or other practices affect surface structure. A schematic diagram of the tension infiltrometer is shown in Fig. 2b. Measurements at negative

heads require good contact between the porous disk and the field soil - in fact, it is essential. A very thin layer of fine sand is helpful in ensuring good contact (Clothier and White, 1981; Watson and Luxmoore, 1986; Perroux and White, 1988).

The approximate analytical solution describing the flow under the tension infiltrometer is given by:

$$Q = \pi a^2 K_t + (a/G)\phi_t \qquad (18)$$

where $K_t = K(\psi_t)$ and

$$\phi_t = \int_{\psi i}^{\psi t} K(\psi) d\psi \qquad (19)$$

The different approaches towards analyzing the data from the tension infiltrometer have already been discussed in the TED report (Kachanoski et al. 1989). Recent developments in the theory suggest that a more simple approach would be to use a single disk at two or more tensions (similar to the pressure infiltrometer approach but with a second mariott bottle) thus obtaining all of the necessary hydraulic properties. As will be discussed, the tension infiltrometer was used on a 10 m transect (20 cm intervals and at three depths) at the Delhi Research Station during the 1989 field season. In the 1989 report, it was suggested that soil moisture conditions should be well below saturation for the tension infiltrometer to function properly. Therefore, the Delhi soil provided a suitable location (i.e a well drained, loamy sand) for testing the tension infiltrometer. At this time, however, the data from the Tension Infiltrometer will not be included in this report because it is still being analyzed as per these recent developments in the theory. A supplementary report will follow upon completion of the analysis.

## 2.3 Instrument Availability

A commercial constant head well permeameter (the Guelph permeameter) is available from Soil Moisture Equipment Corporation, P.O. Box 30025, Santa Barbara, California 95104, U.S.A. A prototype pressure infiltrometer has been developed recently and should be commercially available by 1991.

## 3.0 MATERIALS AND METHODS

### 3.1 Site Selection and Characterization

This project is a continuation from the previous fall (1988) where both hydraulic properties characterization and rainfall simulation were carried out at D. Lobb's farm near Clinton, Ontario. Further studies at this site were undertaken to estimate both the spatial and temporal variation in hydraulic properties.

During the 1989 field season extensive use was also made of different tillage/cropping systems. Table 1 describes the sites where both GPI measurements and rainfall simulation were completed, and the existing management systems. Table 2 shows those sites where only the characterization of hydraulic properties was completed in order to compare the effects of management over a range of textural classes and management schemes.

### 3.2 Methods

As with the 1988 study, paired tillage sites were selected to cover the major soil and topographic changes in the field. Prototype (first generation) pressure infiltrometer attachments for the Guelph permeameter were used to obtain measurements of $K_{fs}$, $\phi_m$ and $\alpha$ on each of the tillage treatments for each of the soil landscape positions. Approximately 4-5 replications were taken in each tillage treatment, with two pressure heads being applied for each replication. At each head, flow was recorded in 30 second intervals until steady state was reached (approximately 15 minutes on average). The steady state flow was recorded and used along with the pressure head to calculate the hydraulic parameters for each replicate (see appendices). Initial and final soil volumetric moisture content was also

Table 1. Description of 1989 field sites sampled for hydraulic properties and rainfall simulation.

| Cooperating Farmer | Location | Tillage* | Soil Texture |
|---|---|---|---|
| Don Lobb (T-2000) | Clinton | MB,NT | SiCL-fSL |
| David Ghent (T-2000) | Mt. Forest | MIN,NT | SiL |
| Frank Anthony (T-2000) | Halton Hills | MIN,MB | L |

min - minimum till
MB - moldboard
NT - no-till

Table 2: Description of 1989 field sites sampled for characterization of hydraulic properties only.

| Cooperating Farmer | Location | Tillage* | Soil Texture |
|---|---|---|---|
| Elora Research Station | Elora | MB,NT | SiL |
| Al Jones (T-2000) | Fingal | RT,SS,MB,NT | SiL |
| Paisley Johnson (T-2000) | Guelph | DC,NT | L-S |

MB - moldboard
NT - no-till
RT - ridgetill
SS - soil-save
DC - disk

recorded using the Time Domain Reflectrometry (TDR) method developed by C. Topp. A field portable Tectronix 1502B cable tester was used, along with two 20 cm TDR probes to measure soil water content. The change in soil water content $\Delta\theta$, along with the measured value of $\phi_m$ was used to predict the time to ponding, Tp during a constant rainfall rate Vo using the equation (Kutilek, 1980):

$$Tp = \frac{(\Delta\theta)\ \phi_m}{Vo^2} \qquad (20)$$

To compare the pressure infiltrometer values to standard laboratory methods, undisturbed cores (50mm diam. x 50mm depth) were taken immediately adjacent to the GPI field reading for determination of Ksat, bulk density, total porosity, soil water characteristic curves $\theta$ ($\Psi$), and estimated pore size distributions. Saturated hydraulic conductivity Ksat was determined using either a constant or falling head method as outlined in Klute et al. (1986).

Soil water characteristic curves were measured using a standard pressure plate apparatus. The undisturbed cores were brought to equilibrium at 0, 10, 25, 50, 100, 330, and 15000 cm pressure values and soil water content determined by water loss from gravimetric weighing. Bulk density was determined from the final oven dry weight of the undisturbed core. Total porosity was calculated from the saturated weight and bulk density calculations. Effective pore size distribution was calculated from capillary rise theory and the soil water characteristic curve, where pore radius, r, is given by:

$$r = 0.15\Psi_m^{-1} \qquad (21)$$

Macroporosity was estimated from the pore size distributions.

The rainfall simulation work that was carried out on three of the sites (Lobb, Ghent and Anthony) used a version of the Guelph Portable Rainfall Simulator (GRSII). The runoff work is part of a Ministry of the Environment research project. A summary of the method is given in Tossell et al. (1987). Two rainfall intensities, low (0.68 $mm \cdot min^{-1}$) and high (2.8 $mm \cdot min^{-1}$) were applied to each tillage treatment. Runoff hydrographs were obtained by measuring runoff in 1 minute intervals. All of the sediment was collected for subsequent analysis of particle size distribution and total phosphorus. The runoff water was filtered on site during the runoff simulation and the water was analyzed for ortho-phosphorus and total hydrolizable phosphorus. Measurement of time to ponding, time to runoff and final steady state infiltration rates were obtained from the rainfall simulation hydrographs. A summary of the data from the 1989 rainfall simulation experiments is given in the 1990 progress report to MOE (J. Eddy).

For this report, each site will be discussed individually, with the appropriate summary tables, while the raw field and laboratory data for each site can be found in separate appendices.

## 4.0 RESULTS AND DISCUSSION FOR 1989 FIELD SEASON

### 4.1 Temporal Changes in Surface Hydraulic Properties

#### 4.1.1 Site Description - D. Lobb, T-2000 Site, Clinton Ontario

One of the main objectives of this study was to examine the effects of tillage on surface hydraulic properties. The 1989 TED report indicated that surface hydraulic conductivity was generally lower in the long term no-till plots compared to the moldboard plough treatment. These measurements were taken immediately prior to fall ploughing. To study the effects of fall tillage on changes in hydraulic properties and runoff characteristics, measurements were again taken in early April before seeding and 3-4 weeks after seeding (i.e June) to estimate any changes with time.

The site selected for the temporal comparison of hydraulic properties was the T-2000 site at Don Lobb's farm, located on concession road 15-16 Goderich Township, just north of Clinton, Ontario (Fig. 4). A detailed description of the site is given in the 1989 TED report. The site has one of the longest running field scale tillage comparisons in Ontario. A no-till system vs. fall moldboard plough has been carried out for 9 years.

The field study was done at the same location as the permanent runoff installations and runoff simulations which are part of the Ministry of the Environment (MOE) research project on event based soil and phosphorous loss. The site is also a Tillage 2000 site and has been benchmarked for detailed soil-tillage-erosion measurements under a different TED project. The surface soil texture changes from a fine sandy loam at the front of the field to a silty clay loam and clay loam at the back of the field.

Four paired tillage sites (soil landscapes) were chosen to cover the major soil and topograhic changes in the field. These sites were located at the same locations as those discussed in the 1989 TED report. Each of the

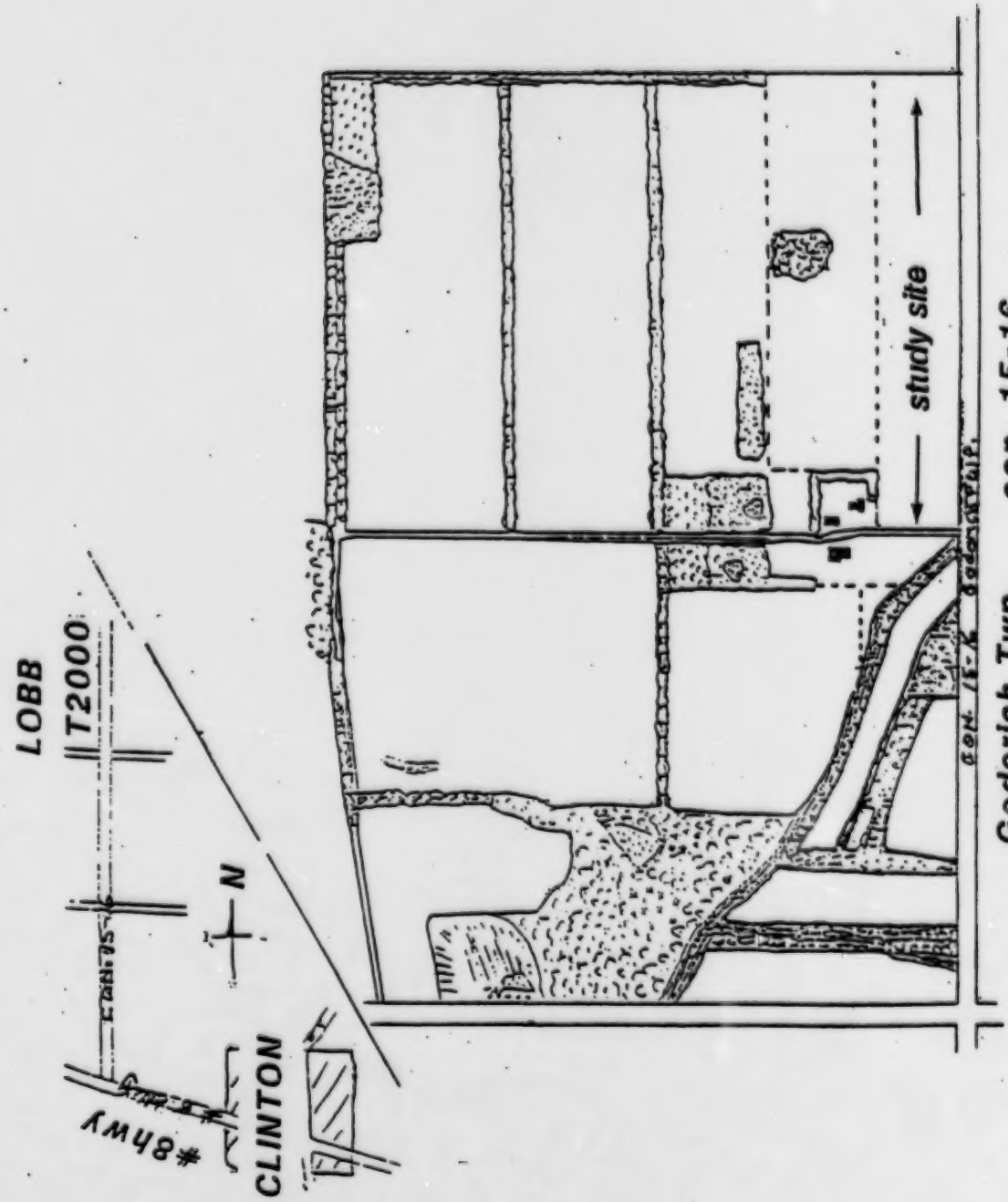



Figure 4. Farm and study site location for D. Lobb T-2000 Site Clinton, Ontario.

sites had two tillage treatments, fall moldboard plough and 9-year no-till (the one year no-till from the previous year had been ploughed). Sampling in April was carried out on two adjacent plot locations, a 10m x 1.6m permanent runoff plot and 1m x 1m rainfall simulation plot. In June, 1989 only the permanent plots were monitored. The information collected allows for a temporal as well as spatial comparison of surface hydraulic properties in the two tillage systems.

4.1.2 Results and Discussion - April Sampling Period

A summary of the data collected for each individual replication of the GPI, along with the calculated hydraulic parameters, is given for both the permanent runoff and 1m x 1m plots in Appendices 2a and 2b respectively. Calculated porosity indices are given in Appendices 2c and 2d for the same plots. Included are measurements of bulk density, soil water content versus matric flux potential $\phi_m$, and calculated pore size distributions for all undisturbed cores sampled in April, 1989.

The field saturated hydraulic conductivity $K_{fs}$ values measured with the GPI during the April sampling period in the permanent runoff plots are given in Table 3. The geometric and arithmetic means were both calculated since $K_{fs}$ generally has a log-normal probability distribution in the field. The data is highly variable within a slope/tillage treatment, but the coefficients of variation are similar to those found in the 1988 TED study at this site, and the data are likely representative of the natural variability in the field. The values for $K_{fs}$ on Hill 1 MB are higher at the lower slope position due to the coarser texture (fine sandy loam) at this site versus that found at the upper slope (silty clay loam). The measured $K_{fs}$ values between treatments at each slope position are generally higher in

Table 3: Summary of $K_{fs}$ from pressure infiltrometer April 1989 - D. Lobb, Clinton, Ontario (Permanent Plots).

| Site/Slope/Tillage | | | Field Saturated Hydraulic Conductivity ($m \cdot s^{-1} \times 10^{-5}$) Replication Number | | | | | | Geometric | | Arithmetic | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | $\bar{X}$ | S | X | S |
| Hill 1 | Lower | MB | 1.84 | 1.22 | 1.84 | 1.07 | | | 1.45 | 1.32 | 1.49 | 0.41 |
| | | NT | 0.475 | 0.512 | 0.146 | 1.36 | - | - | 0.47 | 2.49 | 0.62 | 0.52 |
| | Upper | MB | 0.329 | 0.091 | 0.117 | - | - | - | 0.152 | 1.98 | 0.18 | 0.13 |
| | | NT | 7.35 | 0.439 | 0.165 | - | - | - | 0.81 | 7.18 | 2.65 | 4.07 |
| Hill 2 | Lower | MB | 0.39 | 0.073 | 4.9 | - | - | - | 0.52 | 8.31 | 1.79 | 2.70 |
| | | NT | 0.054 | 0.216 | 0.182 | 0.038 | 0.035 | - | 0.08 | 2.39 | 0.10 | 0.09 |
| | Upper | MB | 11.02 | 9.0 | 6.88 | 8.33 | 0.117 | - | 3.67 | 6.91 | 7.07 | 4.16 |
| | | NT | 0.072 | 0.887 | 0.600 | 1.96 | 0.534 | 3.65 | 0.72 | 3.86 | 1.28 | 1.32 |
| Overall Average | | MB | $3.15^{a1}$ (3.82) | | | | | | | | | |
| | | NT | $1.04^{b}$ (1.81) | | | | | | | | | |

(standard deviation)

[1] Values in the same column with different letters are significantly different at 0.025 probability level

the moldboard when compared to the 9 year no-till treatment. The one exception is the Hill 1 upper slope position where the situation is reversed. Over the entire site however, the $K_{fs}$ value for the moldboard was 2x higher than the 9 year no-till (significant at the 0.025 probability level).

A comparison of the in-situ GPI measurements with the undisturbed cores in the permanent runoff plots is given in Table 4. The $K_{sat}$ values are the average of 3-6 replicates per slope/tillage site. The cores were taken immediately adjacent to the GPI measurements. The correlation coefficient for $K_{fs}$ taken with the GPI versus $K_{sat}$ from the cores is r = 0.42 (significant at 0.05 probability level). In the 1988 study the higher correlation (r = 0.92) was most likely due to the wet soil conditions that existed. Thus the $K_{fs}$ values would more closely approximate the full saturated K values from the core methods (Kachanoski et al., 1989). In this study, initial moisture conditions were much lower, yet the same trends hold with the Ksat values for the MB treatment being significantly higher (0.05 probability) than the NT values.

The results for the GPI readings taken in the smaller 1m x 1m rainfall simulation plots are given in Table 5. These sampling locations are located at the same landscape position and immediately adjacent to the permanent runoff plots and are therefore included as additional replications. It should also be noted that the values for the 9 year no-till plots are missing for Hill 2 due to equipment repair problems. The trend in the data is consistent with the previous data. The moldboard plough treatment has a significantly higher average $K_{fs}$ value than the 9 year no-till treatment (0.05 probability level). A comparison of the $K_{fs}$ and Ksat (core) values from the 1m x 1m plots (Table 6) gave a similar correlation r = 0.47

Table 4: Comparison of $K_{fs}$ from pressure infiltrometer and $K_{sat}$ from undisturbed cores at Clinton, Ontario, April 1989.
(Permanent Plots)

| Site/Slope/Tillage | | | Average $K_{fs}$ (Y) ($m \cdot s^{-1} \times 10^{-5}$) | Undisturbed Core $K_{sat}$ (X) ($m \cdot s^{-1} \times 10^{-5}$) |
|---|---|---|---|---|
| Hill 1 | Lower | MB | 1.49 (0.41) | 163.1 (215.7) |
| | | NT | 0.62 (0.52) | 0.62 (0.2) |
| | Upper | MB | 0.179 (0.13) | 1.38 (2.29) |
| | | NT | 2.65 (4.07) | 2.17 (1.28) |
| Hill 2 | Lower | MB | 1.79 (2.7) | 37.3 (50.3) |
| | | NT | 0.105 (0.09) | 5.51 (5.03) |
| | Upper | MB | 7.07 (4.16) | 98.3 (86.2) |
| | | NT | 1.28 (1.32) | 60.3 (104) |
| Overall Average | | MB | $3.15^{a1}$ | $75.0^{a}$ |
| | | NT | $1.04^{b}$ | $15.7^{b}$ |

(standard deviation)
[1]Values in the same column with different letters are significantly different (0.05 probability level)
Correlation of Y on X r = 0.42
n = 8

Table 5: Summary of $K_{fs}$ for 1m x 1m plots at D. Lobb - April, 1989.

| Site/Slope | | Code | $K_{fs}$ from pressure infiltrometer ($m \cdot s^{-1} \times 10^{-5}$) Moldboard (MB) | No Till (NT) |
|---|---|---|---|---|
| Hill 2 | Lower | 7 | 0.62 | - |
| | | 8 | 0.23 | - |
| | | 9 | - | - |
| Hill 2 | Upper | 10 | 1.84 | - |
| | | 11 | 0.73 | - |
| | | 12 | 6.12 | - |
| Hill 1 | Upper | 13 | 8.05 | 0.12 |
| | | 14 | 3.67 | 0.07 |
| | | 15 | 1.86 | 0.62 |
| | | | $\bar{X}$ - 4.53 | $\bar{X}$ - 0.27 |
| Hill 1 | Lower | 16 | 2.76 | 1.84 |
| | | 17 | 0.41 | 0.11 |
| | | 18 | 0.22 | 0.40 |
| | | | $\bar{X}$ - 1.13 | $\bar{X}$ - 0.78 |
| Overall Average | | | $2.41^{a1}$ (2.6) | $0.53^{b}$ (0.68) |

(standard deviation)
[1]Values in the same row with different letters are significantly different at 0.05 probability level

Table 6: Comparison of $K_{fs}$ from pressure infiltrometer and $K_{sat}$ from undisturbed cores at D. Lobb (April 1989) for 1m x 1m plots.

| Site No. | Average $K_{fs}$ (Y) ($m \cdot s^{-1} \times 10^{-5}$) MB | NT | $K_{sat}$ (X) ($m \cdot s^{-1} \times 10^{-5}$) MB | NT |
|---|---|---|---|---|
| 7 | 0.62 | - | 7.0 | - |
| 8 | 0.23 | - | 14.0 | - |
| 9 | - | - | 29.4 | - |
| 10 | 1.84 | - | 3.65 | - |
| 11 | 0.73 | - | 16.0 | - |
| 12 | 6.12 | - | 385.0 | - |
| 13 | 8.05 | 0.12 | 26.9 | 0.081 |
| 14 | 3.67 | 0.07 | 23.2 | 0.051 |
| 15 | 1.86 | 0.62 | 3.2 | 0.245 |
| 16 | 2.76 | 1.84 | 4.9 | 0.596 |
| 17 | 0.41 | 0.11 | 5.5 | 1.73 |
| 18 | 0.22 | 0.40 | 34.8 | 129.0 |
| Overall Average | $2.41^{a1}$ | $0.53^{b}$ | $46.1^{a}$ | $21.9^{b}$ |
| S.D. | 2.60 | 0.68 | 107.3 | 52.4 |

Correlation of Y on X r = 0.47
n = 17

[1]Values in the same row with different letters are significantly different at the 0.05 probability level

(significant at 0.05 probability level) as the comparison in the large runoff plots (Table 4).

A summary of the average $K_{fs}$ measurements for April, 1990 for both large and small runoff plots is given in Table 7. Both the GPI measurements and data from the standard core method suggest that less, not more water may infiltrate into the no-till treatment. This is identical to the conclusions from the fall data. The data also indicate that the spatial variability of $K_{fs}$ is significantly higher in the MB than in the NT treatment. The standard deviation of the MB is 2x that of the NT treatment.

The GPI method, when combined with measurements of initial and final soil water content measurements in the saturated bulb area (taken with the TDR) also allow other parameters to be calculated which relate to surface runoff. One of these parameters is a predicted effective time to ponding Tp, under steady rainfall. The value of Tp, as discussed earlier in this report, was estimated from (Kutilek, 1980):

$$Tp = \frac{(\theta_f - \theta_i)\phi_m}{Vo^2} \qquad (22)$$

where Tp = time to ponding (s), $\theta_f$ and $\theta_i$ = final and initial soil water content ($m^3 \cdot m^{-3}$), $\phi_m$ = soil matric flux potential ($m^2 \cdot s^{-1}$). The matric flux potential is the unsaturated flow component of steady infiltration and was calculated along with the $K_{fs}$ for each replication, as seen in Appendix 2. A summary of the measured data for predicted Tp at each sampling location for the permanent plots is given in Tables 8 and 9, and summarized in Table 10. Similar calculations for estimated Tp were done for the 1m x 1m plots during the April sampling period and are given in Table 11 and 12, respectively.

Table 7: Overall average of $K_{fs}$ readings for moldboard plough versus no-till by slope position at D. Lobb ($m \cdot s^{-1} \times 10^{-5}$) - April, 1989.

| | | Texture | Moldboard | | No Till | |
|---|---|---|---|---|---|---|
| | | | $\bar{X}$ | S | $\bar{X}$ | S |
| Hill 1 | Lower | fSL | 1.34 | 0.89 | 0.69 | 0.65 |
| | Upper | L | 2.35 | 3.12 | 1.46 | 2.89 |
| Hill 2 | Lower | SiCL | 1.24 | 2.05 | 0.105 | 0.09 |
| | Upper | SiCL | 5.50 | 4.11 | 1.28 | 1.32 |
| Overall Average | | MB | 2.83[a1] | 3.32[A] | 0.91[b] | 1.61[B] |

[1]Values in same row with different letters are significantly different at 0.01 probability level

Table 8: Measured data for calculation of predicted time to ponding, Tp for D. Lobb (permanent plots) April 1989 (Hill 1).

| Site | Mgt | Rep | Soil Water Content θi | θv ($m^3 \cdot m^{-3}$) | Δθ | ϕm ($m^2 \cdot s^{-1}$ x$10^{-6}$) | Calculated Time for Ponding (s) Low Intensity | High Intensity |
|---|---|---|---|---|---|---|---|---|
| Hill 1 | | | | | | | | |
| Lower | MB | 1 | .224 | .372 | .148 | 1.37 | 1579 | 93 |
| | | 2 | .240 | .320 | .08 | 0.425 | 265 | 16 |
| | | 3 | .232 | .307 | .075 | 1.37 | 800 | 47 |
| | | 4 | .214 | .279 | .065 | 1.26 | 638 | 38 |
| | | $\bar{X}$ | .227 | .319 | .092 | 1.11 | 820 | 48 |
| | NT | 1 | .305 | .339 | .034 | 0.392 | 104 | 6 |
| | | 2 | .300 | .339 | .039 | 0.821 | 249 | 15 |
| | | 3 | .285 | .310 | .025 | 0.365 | 71 | 4 |
| | | 4 | .264 | .315 | .051 | 1.82 | 723 | 43 |
| | | $\bar{X}$ | .288 | .326 | .037 | 0.849 | 287 | 17 |
| Upper | MB | 1 | .279 | .330 | .051 | 0.465 | 185 | 11 |
| | | 2 | .290 | .344 | .054 | 0.032 | 13 | <1 |
| | | 3 | .295 | .330 | .035 | 0.065 | 18 | 1 |
| | | $\bar{X}$ | .288 | .335 | 4.7 | 0.187 | 72 | 4 |
| | NT | 1 | .274 | .350 | .076 | 4.27 | 2527 | 149 |
| | | 2 | .269 | .363 | .094 | 0.62 | 454 | 27 |
| | | 3 | .264 | .344 | .080 | 0.434 | 270 | 16 |
| | | $\bar{X}$ | .269 | .352 | .083 | 1.77 | 1084 | 64 |

Low Intensity Rainfall Rate = 0.68 $mm \cdot min^{-1}$
High Intensity Rainfall Rate = 2.8 $mm \cdot min^{-1}$

Table 9: Measured data for calculation of predicted time to ponding, Tp, for D. Lobb (permanent plots) April 1989 Hill 2.

| Site | Mgt | Rep | Soil Water Content θi | θv ($m^3 \cdot m^{-3}$) | Δθ | ϕm ($m^2 \cdot s^{-1}$ x$10^{-6}$) | Calculated Time for Ponding (s) Low Intensity | High Intensity |
|---|---|---|---|---|---|---|---|---|
| Hill 2 | | | | | | | | |
| Lower | MB | 1 | .274 | .358 | 0.084 | 0.390 | 255 | 15 |
| | | 2 | .279 | .344 | 0.065 | 0.073 | 37 | 2 |
| | | 3 | .274 | .354 | 0.080 | 4.89 | 3047 | 180 |
| | | $\bar{X}$ | .276 | .352 | 0.076 | 1.78 | 1113 | 66 |
| | NT | 1 | .295 | .339 | 0.044 | 0.034 | 12 | <1 |
| | | 2 | .330 | .376 | 0.046 | 0.190 | 68 | 4 |
| | | 3 | .305 | .344 | 0.039 | 0.100 | 30 | 2 |
| | | 4 | .310 | .344 | 0.034 | 0.020 | 6 | <1 |
| | | 5 | .279 | .330 | 0.051 | 0.022 | 9 | <1 |
| | | $\bar{X}$ | .304 | .347 | 0.043 | 0.073 | 25 | 1 |
| Upper | MB | 1 | .320 | .390 | 0.070 | 10.69 | 5828 | 345 |
| | | 2 | .305 | .406 | 0.101 | 19.1 | 15024 | 889 |
| | | 3 | .335 | .381 | 0.046 | 6.88 | 2465 | 146 |
| | | 4 | .269 | .354 | 0.085 | 6.10 | 4038 | 239 |
| | | 5 | .274 | .344 | 0.070 | 0.102 | 55 | 3 |
| | | $\bar{X}$ | .301 | .375 | 0.074 | 8.57 | 5482 | 324 |
| | NT | 1 | .315 | .363 | 0.048 | 0.129 | 48 | 3 |
| | | 2 | .344 | .376 | 0.032 | 1.58 | 394 | 23 |
| | | 3 | .354 | .385 | 0.031 | 0.989 | 239 | 14 |
| | | 4 | .325 | .372 | 0.047 | 1.69 | 619 | 37 |
| | | 5 | .315 | .385 | 0.070 | 0.936 | 510 | 30 |
| | | 6 | .295 | .422 | 0.127 | 7.03 | 6953 | 411 |
| | | $\bar{X}$ | .325 | .384 | 0.059 | 2.06 | 1460 | 86 |

Low Intensity Rainfall Rate = 0.68 $mm \cdot min^{-1}$
High Intensity Rainfall Rate = 2.8 $mm \cdot min^{-1}$

Table 10: Comparison of predicted time to ponding for tillage treatments at D. Lobb April 1989 (permanent plots).

| Site/Slope | | Rain Intensity | Calculated Time to Ponding Tp (s) MB | NT |
|---|---|---|---|---|
| Hill 1 | Lower | Low | 820 (553) | 287 (301) |
| | | High | 48 (32) | 17 (18) |
| | Upper | Low | 72 (98) | 1084 (1253) |
| | | High | 4 (6) | 64 (74) |
| Hill 2 | Lower | Low | 1113 (1678) | 25 (26) |
| | | High | 66 (99) | 1 (1) |
| | Upper | Low | 5482 (5740) | 1460 (2698) |
| | | High | 324 (340) | 86 (159) |
| Overall Average | | Low | 1872[a1] (2446) | 714[a] (671) |
| | | High | 110[a] (145) | 42[a] (40) |

(standard deviation)
[1]Values in the same row with different letters are signifi antly different at the 0.05 probability level

Table 11: Measured data for calculation of predicted time to ponding, Tp for D. Lobb (1m x 1m plots) April 1989.

| Site | No. | | Soil Water Content ($m^3 \cdot m^{-3}$) | | $\phi m$ ($m^2 \cdot s^{-1}$ $x10^{-6}$) | | Calculated Time to Ponding (s) Low Intensity | High Intensity |
|---|---|---|---|---|---|---|---|---|
| MB | 7 | | .315 | .358 | .043 | 0.285 | 95 | 6 |
| | 8 | | .305 | .325 | .020 | 0.224 | 35 | 2 |
| | 9 | | .335 | .394 | .059 | 0.314 | 144 | 8 |
| | | $\bar{X}$ | .318 | .359 | .041 | 0.274 | 91 | 5 |
| | 10 | | .259 | .349 | .090 | 1.98 | 1388 | 82 |
| | 11 | | .310 | .426 | .116 | 2.88 | 2602 | 154 |
| | 12 | | .320 | .390 | .070 | 3.34 | 1821 | 108 |
| | | $\bar{X}$ | .296 | .388 | .092 | 2.74 | 1937 | 115 |
| | 13 | | .274 | .390 | .116 | 5.84 | 5276 | 312 |
| | 14 | | .269 | .398 | .129 | 1.52 | 1527 | 90 |
| | 15 | | .310 | .402 | .092 | 0.605 | 433 | 26 |
| | | $\bar{X}$ | .284 | .397 | .112 | 2.65 | 2412 | 143 |
| | 16 | | .253 | .376 | .123 | 1.45 | 1389 | 82 |
| | 17 | | .232 | .320 | .088 | 0.577 | 395 | 23 |
| | 18 | | .274 | .344 | .070 | 0.091 | 50 | 3 |
| | | $\bar{X}$ | .253 | .347 | .094 | 0.706 | 611 | 36 |
| NT | 13 | | .295 | .349 | .055 | 0.219 | 94 | 5 |
| | 14 | | .295 | .330 | .044 | 0.039 | 13 | <1 |
| | 15 | | .274 | .354 | .080 | 0.903 | 563 | 33 |
| | | $\bar{X}$ | .288 | .347 | .060 | 0.387 | 223 | 13 |
| | 16 | | .253 | .349 | .096 | 4.43 | 3312 | 196 |
| | 17 | | .285 | .354 | .069 | 0.082 | 44 | 3 |
| | 18 | | .269 | .339 | .070 | 0.264 | 144 | 8 |
| | | $\bar{X}$ | .269 | .347 | .078 | 1.59 | 1167 | 69 |

Low Intensity Rainfall Rate = 0.68 $mm \cdot min^{-1}$
High Intensity Rainfall Rate = 2.8 $mm \cdot min^{-1}$

Table 12. Comparison of predicted time to ponding for tillage treatments at D. Lobb (1m x 1m plots) - April, 1989.

| Site/Slope | Rain Intensity | Calculated Time to Ponding Tp(s) MB | NT |
|---|---|---|---|
| Hill 1 Lower | LOW | 611 (695) | 1167 (1858) |
| | HIGH | 36 (41) | 69 (110) |
| Upper | LOW | 2412 (2540) | 223 (297) |
| | HIGH | 143 (150) | 13 (17) |
| Hill 2 Lower | LOW | 91 (55) | - |
| | HIGH | 5 (3) | - |
| Upper | LOW | 1937 (615) | - |
| | HIGH | 115 (36) | - |
| Overall Average | LOW | 1263[a1] (1091) | 695 (667) |
| | HIGH | 75[a] (90) | 41[a] (77) |

(standard deviation)
[1]Values in the same row with different letters are significantly different at the 0.05 probability level.

The overall average Tp for each slope position over both large and small plots is given for each treatment in Table 13. The data predicts that on average time to ponding would be much lower in the 9 year no-till treatment than in the moldboard. The Tp values are quite variable between sites which negated any statistical difference, but all sites at both intensities had lower Tp for the NT compared to MB. This data can now be compared to the observed data from the rainfall simulation experiments carried out under the Ministry of the Environment (MOE) project on the same soil landscape positions. During the April sampling period rainfall simulation trials were completed only on the 1m x 1m plots. Table 14 illustrates the observed runoff at the high (2.8 $mm \cdot min^{-1}$) rainfall intensity for the 1m x 1m plots. The data are consistent with that reported in the 1989 TED study from the site where the no-till results in higher runoff rates (lower infiltration) than the moldboard system. However, as in the fall data, the total soil loss and phosphorus loss from the moldboard treatment were higher.

The low intensity data for Lobb during the April sampling period is not summarized because the low intensity storm failed to generate any runoff or soil loss from the moldboard site. Thus under very low intensity rains, no-till may have higher soil and P loss rates because runoff is generated in the no-till and not in the moldboard. For high intensity storms the moldboard again generates less water runoff than the no-till, but the water which runs off is laden with sediment and phosphorus. This illustrates the need to interpret single event data very carefully and depending on the event characteristics you would reach opposite conclusions.

The runoff data in Table 14 are consistent with the predicted values for Tp and measured surface hydraulic properties. A comparison of the

Table 13: Comparison of overall average predicted time to ponding for April sampling period (D. Lobb).

| Site/Slope | | Rain Intensity | Calculated Time to Ponding MB | NT |
|---|---|---|---|---|
| Hill 1 | Lower | Low | 715 | 727 |
| | | High | 42 | 43 |
| | Upper | Low | 1242 | 653 |
| | | High | 73 | 38 |
| Hill 2 | Lower | Low | 602 | 25 |
| | | High | 35 | 1 |
| | Upper | Low | 3709 | 1460 |
| | | High | 219 | 86 |
| Overall Average | | Low | 1567[a1] (1455) | 726[a] (587) |
| | | High | 92[a] (86) | 42[a] (35) |

(standard deviation)
[1]Values in the same row with different letters are significantly different at 0.05 probability level.

Table 14: Runoff characteristics of Lobb simulation (2.8 mm $min^{-1}$ for 12 min.) in April, 1988.

| Site/Slope/Tillage | | | Time to Ponding (sec) | Water runoff (cm) | Steady-state runoff rate (cm/hr) | Steady-state infiltration (cm/hr) | Soil loss (t/ha) | Total Phosphorus Loss (kg/ha) |
|---|---|---|---|---|---|---|---|---|
| Hill #1 | Lower | MB | 40 | 1.18 | 8.3 | 7.5 | 3.8 | 5.8 |
| | | NT | 30 | 1.53 | 11.4 | 5.4 | 1.72 | 1.25 |
| | Upper | MB | 25 | 0.71 | 8.1 | 8.7 | 4.2 | 1.30 |
| | | NT | 22 | 1.70 | 12.4 | 4.4 | 0.5 | 0.36 |
| Hill #2 | Lower | MB | 10 | 0.33 | 3.1 | 13.7 | 1.38 | 0.45 |
| | | NT | 13 | 0.84 | 7.4 | 8.4 | 0.85 | 0.57 |
| | Upper | MB | 12 | 0.10 | 2.0 | 14.8 | 0.65 | 0.26 |
| | | NT | 11 | 1.21 | 10.4 | 6.4 | 1.70 | 1.28 |
| | Avg. | MB | 24 | 0.60 | 5.6 | 11.2 | 2.5 | 1.98 |
| | | NT | 19 | 1.32 | 10.4 | 6.4 | 1.2 | 0.87 |

measured time to runoff $T_R$ and predicted time to ponding are given in Table 15 and indicate a good relationship. Even the zero runoff from the moldboard treatment under low intensity is predicted by the Tp estimate.

Both the values for $K_{fs}$ and Ksat indicate that more runoff would be expected in the no-till treatment. The overall average Ksat and $K_{fs}$ values for the April period (Table 16) are 1.9x and 4.3x higher, respectively in the moldboard compared to the 9 year no-till plots though the difference was not significant (0.05 probability level). This is similar to the 1.8x higher steady state infiltration rate in the moldboard (Table 14). In addition, the soil matric flux potential $\phi_m$ is also lower (significant at 0.05 probability level) in the no-till compared to the moldboard (Tables 17, 18 and 19). The lower $\phi_m$ and higher initial soil water contents in the no-till resulted in considerably shorter predicted time to ponding, which was also observed in the rainfall simulation trials.

The changes in surface hydraulic properties and subsequent effects on the runoff and soil loss are probably a result of increased bulk density and lower overall soil porosity in the no-till compared to moldboard as shown in the 1989 TED study. The measured porosity indices for each of the soil cores taken in both the permanent and 1m x 1m plots are given in Tables 20 and 21 respectively. A summary of this data are given in Table 22. The average bulk density values in the no-till is 12% higher than the moldboard and the total porosity of the no-till is 0.45 $m^3 \cdot m^{-3}$ compared to 0.494 $m^3 \cdot m^{-3}$ in the MB treatment. The decrease of 0.045 $m^3 \cdot m^{-3}$ of total porosity in the no-till is identical to the measured decrease in the macroporosity of 0.045 $m^3 \cdot m^{-3}$, in the NT compared to the MB treatment. The decreased macroporosity would therefore account for the decreased infiltration, Ksat, $K_{fs}$ and increased water runoff observed in the no-till plots.

Table 15 : Comparison of measured time to runoff $T_R$ and predicted time to ponding $T_p$.

| Rainfall Intensity | MB | | NT | |
|---|---|---|---|---|
| | $T_p$ | $T_R$ | $T_p$ | $T_R$ |
| | sec | | | |
| Low | 1567 | >1500 | 716 | 726 |
| High | 92 | 183 | 42 | 98 |

Table 16: Comparison of $K_{fs}$ and $K_{sat}$ for overall average at D. Lobb, 1989.

| Site/Slope/Tillage | | | Average $K_{fs}$ (Y) ($m \cdot s \times 10^{-5}$) | Average $K_{sat}$ |
|---|---|---|---|---|
| Hill 1 | Lower | MB | 1.34 (0.89) | 99.67 (172 |
| | | NT | 0.69 (0.65) | 19.12 (48. |
| | Upper | MB | 2.35 (3.12) | 8.4 (11.5 |
| | | NT | 1.46 (2.89) | 1.29 (1.4 |
| Hill 2 | Lower | MB | 1.24 (2.05) | 24.0 (29. |
| | | NT | 0.10 (0.09) | 5.51 (5.0 |
| | Upper | MB | 5.50 (4.11) | 112.0 (134 |
| | | NT | 1.28 (1.32) | 60.3 (104 |
| Overall Average | | MB | 2.61[a] (1.99) | 61.02[a] (52 |
| | | NT | 0.88[a] (0.62) | 21.55[a] (26 |

(standard deviation)
Values in each column with different letters are significantly differe
0.05 probability level

Correlation of Y on X  r = 0.62
n = 8

Table 17: Summary of tillage effect on average Matric Flux Potential $\phi_m$ measurements for D. Lobb April 1989 (permanent plots).

| | | Matric Flux Potential ($m^2 \cdot s^{-1} \times 10^{-6}$) | | Initial Soil Water Content ($m^3 \cdot m^{-3}$) | |
|---|---|---|---|---|---|
| | | MB | NT | MB | NT |
| Hill 1 | Lower | 1.11 | 0.85 | 22.7 | 28.8 |
| | Upper | 0.19 | 1.77 | 28.8 | 26.9 |
| Hill 2 | Lower | 1.78 | 0.07 | 27.6 | 30.4 |
| | Upper | 8.57 | 2.06 | 30.1 | 32.5 |
| Overall Average[1] | | 3.55[a**] | 1.19[b**] | 27.4[a*] | 30.1[b*] |
| S.D. | | 5.38 | 1.79 | 3.44 | 2.64 |

[1]Values for each treatment with different letters are significantly different at: (1) * 0.01 probability level (2)** 0.05 probability level

Table 18: Summary of tillage effects on average matric flux potential $\phi m$ for D. Lobb 1m x 1m plots (April 1989).

| | | Matric Flux Potential ($m^2 \cdot s^{-1} \times 10^{-6}$) | | Initial Soil Water Content (%) | |
|---|---|---|---|---|---|
| | | MB | NT | MB | NT |
| Hill 1 | Lower | 0.71 | 1.59 | 25.3 | 26.9 |
| | Upper | 2.65 | 0.39 | 28.4 | 28.8 |
| Hill 2 | Lower | 0.27 | - | 31.8 | - |
| | Upper | 2.74 | - | 29.6 | - |
| Overall Average | | $1.59^{a1}$ | $0.99^{a}$ | $28.8^{a}$ | $27.8^{a}$ |
| S.D. | | 1.72 | 1.71 | 3.19 | 1.64 |

[1]Values in same row with different letters are significantly different at 0.05 probability level.

Table 19: Summary of tillage effects on overall average matric flux potential $\phi m$ for D. Lobb April sampling period.

| | | Matric Flux Potential ($m^2 \cdot s^{-1} \times 10^{-6}$) | | Initial Soil Water Content (%) | |
|---|---|---|---|---|---|
| | | MB | NT | MB | NT |
| Hill 1 | Lower | 0.91 | 1.22 | 24.0 | 27.8 |
| | Upper | 1.42 | 1.08 | 28.6 | 27.8 |
| Hill 2 | Lower | 1.02 | 0.07 | 31.8 | 30.4 |
| | Upper | 5.65 | 2.06 | 29.6 | 32.5 |
| Overall Average[1] | | $2.68^{a*}$ | $1.14^{b*}$ | $28.0^{a**}$ | $29.6^{b**}$ |
| S.D. | | 4.22 | 1.73 | 3.35 | 2.60 |

[1]Values for each treatment with different letters are significantly different at: (1)* 0.05 probability level (2)** at 0.025 probability level

Table 20: Summary of porosity indices from undisturbed cores for Clinton, Ontario April 1989 (Permanent Runoff Plots)

| Site/Slope/Rep. | | | Bulk Density ($g \cdot m^{-3}$) | | Porosity ($m^3 \cdot m^{-3}$) | | Macroporosity ($m^3 \cdot m^{-3}$) | | Relative Macroporosity (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | MB | NT | MB | NT | MB | NT | MB | NT |
| Hill 1 | Lower | 1 | 1.45 | 1.43 | 0.474 | 0.476 | 0.069 | 0.048 | 14.5 | 10.1 |
| | | 2 | 1.39 | 1.41 | 0.467 | 0.473 | 0.066 | 0.044 | 14.1 | 9.3 |
| | | 3 | 1.43 | 1.50 | 0.458 | 0.446 | 0.061 | 0.042 | 13.3 | 9.4 |
| | | 4 | 1.52 | 1.57 | 0.433 | 0.398 | 0.039 | 0.039 | 9.0 | 9.8 |
| | $\bar{X}$ | | 1.45 | 1.48 | 0.458 | 0.448 | 0.059 | 0.043 | 4.7 | 9.6 |
| | Upper | 1 | 1.50 | 1.61 | 0.452 | 0.452 | 0.045 | 0.070 | 9.9 | 15.5 |
| | | 2 | 1.57 | 1.67 | 0.424 | 0.390 | 0.046 | 0.037 | 10.8 | 9.5 |
| | | 3 | 1.62 | 1.56 | 0.414 | 0.458 | 0.049 | 0.063 | 11.8 | 13.7 |
| | | 4 | 1.53 | 1.70 | 0.416 | 0.449 | 0.029 | 0.074 | 7.0 | 16.1 |
| | $\bar{X}$ | | 1.55 | 1.63 | 0.426 | 0.437 | 0.042 | 0.061 | 9.9 | 13.8 |
| Hill 2 | Lower | 1 | 1.32 | 1.77 | 0.534 | 0.425 | 0.162 | 0.036 | 30.3 | 8.5 |
| | | 2 | 1.48 | 1.63 | 0.498 | 0.472 | 0.087 | 0.063 | 17.5 | 13.3 |
| | | 3 | - | 1.62 | - | 0.446 | - | 0.045 | - | 10.1 |
| | | 4 | - | 1.64 | - | 0.431 | - | 0.050 | - | 11.6 |
| | $\bar{X}$ | | 1.4 | 1.66 | 0.516 | 0.443 | 0.124 | 0.048 | 23.9 | 10.9 |
| | Upper | 1 | 1.46 | 1.50 | 0.507 | 0.461 | 0.103 | 0.034 | 22.3 | 7.4 |
| | | 2 | 1.23 | 1.44 | 0.532 | 0.484 | 0.173 | 0.054 | 32.5 | 11.1 |
| | | 3 | 1.39 | - | 0.514 | - | 0.107 | - | 20.8 | - |
| | | 4 | 1.36 | 1.62 | 0.537 | 0.442 | 0.137 | 0.030 | 25.5 | 6.8 |
| | | 5 | 1.44 | 1.65 | 0.515 | 0.457 | 0.124 | 0.040 | 24.1 | 8.7 |
| | | 6 | - | 1.50 | - | 0.497 | - | 0.077 | - | 15.5 |
| | $\bar{X}$ | | 1.38 | 1.54 | 0.521 | 0.468 | 0.129 | 0.047 | 25.0 | 8.4 |

Table 21: Summary of porosity indices for undisturbed cores - Clinton, Ontario
April, 1989 (1m x 1m plots)

| Site/Slope/Rep. | | | Bulk Density ($g \cdot m^{-3}$) | | Porosity ($m^3 \cdot m^{-3}$) | | Macroporosity ($m^3 \cdot m^{-3}$) | | Relative Macroporosity (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | MB | NT | MB | NT | MB | NT | MB | NT |
| Hill 1 | Lower | 18 | 1.33 | 1.48 | 0.502 | 0.459 | 0.066 | 0.042 | 13.1 | 9.1 |
| | | 17 | 1.31 | 1.41 | 0.499 | 0.476 | 0.078 | 0.052 | 15.6 | 10.9 |
| | | 16 | 1.30 | 1.37 | 0.514 | 0.491 | 0.071 | 0.056 | 13.8 | 11.4 |
| | $\bar{X}$ | | 1.31 | 1.42 | 0.505 | 0.475 | 0.072 | 0.050 | 14.2 | 10.5 |
| | Upper | 15 | 1.44 | 1.72 | 0.472 | 0.394 | 0.088 | 0.031 | 18.6 | 7.1 |
| | | 14 | 1.38 | 1.65 | 0.497 | 0.409 | 0.138 | 0.051 | 27.8 | 12.5 |
| | | 13 | 1.36 | 1.56 | 0.490 | 0.426 | 0.107 | 0.043 | 21.8 | 10.1 |
| | $\bar{X}$ | | 1.39 | 1.64 | 0.486 | 0.410 | 0.111 | 0.042 | 22.7 | 10.2 |
| Hill 2 | Upper | 12 | 1.19 | | 0.526 | | 0.140 | | 26.6 | |
| | | 11 | 1.41 | | 0.528 | | 0.095 | | 18.0 | |
| | | 10 | 1.39 | | 0.535 | | 0.085 | | 15.9 | |
| | $\bar{X}$ | | 1.33 | | 0.530 | | 0.107 | | 20.2 | |
| | Lower | 9 | 1.25 | | 0.547 | | 0.160 | | 29.2 | |
| | | 8 | 1.40 | | 0.537 | | 0.115 | | 21.4 | |
| | | 7 | 1.42 | | 0.488 | | 0.074 | | 15.2 | |
| | $\bar{X}$ | | 1,36 | | 0.524 | | 0.116 | | 21.9 | |

Table 22. Summary of average treatment effects on porosity indices from all cores sampled at D. Lobbs - April 1989 sampling period.

| Site/Slope | Bulk Density ($g \cdot cm^{-3}$) | | Total Porosity ($m^3 \cdot m^{-3}$) | | Macroporosity ($m^3 \cdot m^{-3}$) | | Relative Macroporosity (%) | |
|---|---|---|---|---|---|---|---|---|
| | MB | NT | MB | NT | MB | NT | MB | NT |
| Hill 1 Lower | 1.39 | 1.45 | 0.478 | 0.460 | 0.065 | 0.046 | 13 4 | 10.0 |
| Upper | 1.48 | 1.64 | 0.452 | 0.425 | 0.016 | 0.051 | 16.3 | 12.0 |
| Hill 2 Lower | 1.37 | 1.54 | 0.521 | 0.443 | 0.12 | 0.048 | 22.0 | 10.9 |
| Upper | 1.36 | 1.66 | 0.524 | 0.468 | .118 | 0.047 | 22.1 | 8.4 |
| Average | 1.4[a1] | 1.57[b] | 0.494[a] | 0.449[b] | 0.093[a] | 0.048[b] | 18.4[a] | 10.3[b] |
| S.D. | 0.10 | 0.11 | 0.039 | 0.03 | 0.04 | 0.013 | 4.32 | 1.52 |

[1] Values for each soil parameter with different letters are significantly different at the 0.01 probability level

4.1.3 D. Lobb - June Sampling Period

The Lobb site was again sampled in June of 1989 after the crop had emerged to see the effects of time, secondary tillage and planting on the surface hydraulic properties. A third sampling location, Hill No.3 was also sampled because of its different texture (i.e clay loam). During this sampling period, only the permanent runoff plots were sampled because the 1m x 1m sites had been disturbed by field crews working in the area. Raw field data from the GPI readings are seen in Appendix 2e. All readings were taken near the middle of the corn row to reduce disturbance of the emerging corn crop. Undisturbed cores were not taken at this time so as to minimize site disturbance for future rainfall simulation runs.

A summary of the measured $K_{fs}$ values for each replicate are seen in Table 23. The overall average $K_{fs}$ indicates that the moldboard treatment is approximately 2.5x higher than the no-till.

Table 24 and 25 show the measured values for calculation of the predicted time to ponding Tp for Hill 1 and 2, respectively. A summary of this data can be found in Table 26. The matric flux potential is again lower in the no-till compared to the moldboard (Table 27). The lower $\phi_m$ and higher initial soil water contents in the no-till result in a shorter predicted time to ponding in the no-till which is consistent with the other sampling periods.

The measured data from the rainfall simulation experiments seen in Table 28 are consistent with the measured hydraulic properties for this site. Infiltration rates in the no-till were on average higher, but not significantly different than those in the moldboard plots.

Table 23: Summary of field saturated hydraulic conductivity from pressure infiltrometer for D.Lobb, June 1989 sampling period.

| Site/Slope/ Tillage | | | Field saturated $K_{fs}$ ($m \cdot s^{-1} \times 10^{-5}$) Replication Number 1 | 2 | 3 | 4 | 5 | Geometric $\bar{X}$ | Geometric S | Arithmetic $\bar{X}$ | Arithmetic S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hill 1 | Lower | MB | 11.17 | 0.915 | 0.986 | 2.26 | | 2.18 | 3.20 | 3.83 | 4.93 |
| | | NT | 4.47 | 5.51 | 0.145 | 5.02 | - | 2.06 | 5.87 | 3.79 | 2.46 |
| | Upper | MB | 0.059 | 2.62 | 3.17 | 0.037 | - | 0.37 | 10.90 | 1.47 | 1.66 |
| | | NT | 0.073 | 0.355 | 2.74 | 1.16 | - | 0.53 | 4.81 | 1.08 | 1.20 |
| Hill 2 | Lower | MB | 28.00 | 3.61 | 0.816 | - | - | 4.35 | 5.90 | 1.08 | 14.9 |
| | | NT | 0.667 | 3.17 | 1.46 | - | - | 1.46 | 2.18 | 1.76 | 1.28 |
| | Upper | MB | 4.53 | 0.146 | 0.013 | 19.6 | 2.66 | 0.85 | 18.9 | 5.39 | 8.16 |
| | | NT | 0.580 | 0.013 | 0.195 | 0.854 | - | 0.19 | 6.61 | 0.41 | 0.38 |
| Hill 3 | Upper | MB | 2.35 | 1.28 | 0.195 | 0.203 | - | 0.59 | 3.58 | 1.01 | 1.03 |
| | | NT | 0.382 | 3.23 | 1.07 | - | - | 1.10 | 2.91 | 1.56 | 1.49 |
| Overall Average | | MB | $4.50^{a1}$ (7.28) | | | | | | | | |
| | | NT | $1.72^{a}$ (1.82) | | | | | | | | |

(standard deviation)
[1]Values with different letters are significantly different at the 0.05 probability level

Table 24: Measured data for calculation of predicted time to ponding Tp for D. Lobb, June 1989 (Hill 1)

| Site | Mgt. | Rep. | Soil Water Content θi | θv ($m^3 \cdot m^{-3}$) | Δθ | ϕm ($m^2 \cdot s^{-1} \times 10^{-6}$) | Calculated Time to ponding Tp(s) Low Intensity | High Intensity |
|---|---|---|---|---|---|---|---|---|
| Hill 1 | Lower | MB | | | | | | |
| | | 1 | .206 | .445 | .239 | 16.52 | 30750 | 1819 |
| | | 2 | .211 | .362 | .151 | 1.23 | 1446 | 86 |
| | | 3 | .222 | .344 | .122 | 1.26 | 1197 | 71 |
| | | 4 | .296 | .376 | .170 | 1.63 | 2158 | 128 |
| | | $\bar{X}$ | .211 | .382 | .1705 | 5.16 | 8888 | 526 |
| | | NT | | | | | | |
| | | 1 | .237 | .398 | .161 | 5.73 | 7185 | 425 |
| | | 2 | .200 | .367 | .167 | 6.45 | 8389 | 496 |
| | | 3 | .216 | .315 | .099 | 0.584 | 450 | 27 |
| | | 4 | .211 | .367 | .156 | 5.59 | 6791 | 402 |
| | | $\bar{X}$ | .216 | .362 | .146 | 4.56 | 5704 | 337 |
| | Upper | MB | | | | | | |
| | | 1 | .274 | .353 | .079 | 0.117 | 72 | 4 |
| | | 2 | .279 | .353 | .074 | 5.56 | 3204 | 190 |
| | | 3 | .259 | .376 | .117 | 5.85 | 5331 | 315 |
| | | 4 | .285 | .358 | .073 | 0.114 | 65 | 4 |
| | | $\bar{X}$ | .274 | .360 | .086 | 2.91 | 2168 | 128 |
| | | NT | | | | | | |
| | | 1 | .264 | .393 | .129 | 0.076 | 76 | 4 |
| | | 2 | .274 | .362 | .088 | 0.308 | 211 | 12 |
| | | 3 | .290 | .371 | .081 | 3.21 | 2025 | 120 |
| | | 4 | .211 | .289 | .078 | 0.36 | 219 | 13 |
| | | $\bar{X}$ | .260 | .354 | .094 | 0.99 | 633 | 37 |

Low Intensity Rainfall Rate = 0.68 $mm \cdot min^{-1}$
High Intensity Rainfall Rate = 2.8 $mm \cdot min^{-1}$



Table 25: Measured data for calculation of predicted Tp for D. Lobb, Hill 2 June, 1989 sampling period.

| Site | Mg+ | Rep | Soil Water Content θi | θv ($m^3 \cdot m^{-3}$) | Δθ | ϕm ($m^2 \cdot s^{-1} \times 10^{-6}$) | Calculated Tp(s) Low Intensity | High Intensity |
|---|---|---|---|---|---|---|---|---|
| Hill 2 | | | | | | | | |
| Lower | MB | 1 | - | - | - | 28.00 | - | - |
| | | 2 | - | - | - | 7.29 | - | - |
| | | 3 | .285 | .402 | .117 | 0.816 | 743 | 44 |
| | | $\bar{X}$ | .285 | .402 | .117 | 12.03 | 743 | 44 |
| | NT | 1 | - | - | - | 0.35 | - | - |
| | | 2 | .259 | .418 | .159 | 2.44 | 3021 | 179 |
| | | 3 | .264 | .422 | .158 | 0.728 | 896 | 53 |
| | | $\bar{X}$ | .2615 | .420 | .1585 | 1.17 | 1959 | 116 |
| Upper | MB | 1 | .339 | .422 | .083 | 3.51 | 2269 | 134 |
| | | 2 | .339 | .422 | .083 | 0.694 | 449 | 26 |
| | | 3 | .339 | .422 | .083 | 0.0089 | 6 | <1 |
| | | 4 | - | - | - | 12.50 | - | - |
| | | 5 | - | - | - | 1.78 | - | - |
| | | $\bar{X}$ | .339 | .422 | .083 | 3.70 | 908 | 53 |

Low Intensity Rainfall Rate = 0.68 $mm \cdot min^{-1}$
High Intensity Rainfall Rate = 2.8 $mm \cdot min^{-1}$

Table 26: Comparison of average predicted Tp for tillage treatments at D. Lobb for June, 1989 sampling period.

| Site | Slope | Rain Intens. | Calculated Time to ponding Tp(s) Moldboard | NoTill |
|---|---|---|---|---|
| Hill 1 | | | | |
| | Lower | Low | 8888 | 5704 |
| | | High | 526 | 337 |
| | Upper | Low | 2168 | 633 |
| | | High | 128 | 37 |
| Hill 2 | | | | |
| | Lower | Low | 743 | 1958 |
| | | High | 44 | 116 |
| | Upper | Low | 908 | 1 |
| | | High | 53 | <1 |
| Overall Average | | Low | 3176[a1] (3860) | 2074[a] (2554) |
| | | High | 187[a] (229) | 123[a] (151) |

(standard deviation)
[1]Values in same row with different letters are significantly different at 0.05 probability level

Table 27: Summary of tillage effects on average matric flux potential measurements at D. Lobb for June sampling period.

| | | Matric Flux Potential ($m^2 \cdot s^{-1}$ x$10^{-6}$) | | Initial Soil Water Content (%) | |
|---|---|---|---|---|---|
| | | MB | NT | MB | NT |
| Hill 1 | Lower | 5.2 | 4.6 | 21.1 | 21.6 |
| | Upper | 2.9 | 0.99 | 27.4 | 26.0 |
| Hill 2 | Lower | 12.0 | 1.17 | 28.5 | 26.1 |
| | Upper | 3.7 | 0.25 | 33.9 | - |
| Overall Average[1] | | 5.43[a] | 1.79[b] | 27.7[a] | 24.6[a] |
| S.D. | | 7.67 | 2.32 | 4.74 | 2.57 |

[1]Values for each treatment with different letters are significantly different at 0.05 probability level

Table 28: Runoff characteristics from D. Lobb rainfall simulation in June 1989 for large plots.

| | | | Runoff Rate (cm/hr) | Infilt Rate (cm/hr) | Soil Loss (t/ha) | Time to Runoff (S) |
|---|---|---|---|---|---|---|
| Hill#1 | Lower | NT | 11.5 | 6.6 | 7.0 | 120 |
| | | MB | 11.5 | 6.6 | 16.0 | 60 |
| | Upper | NT | 8.5 | 9.6 | 9.0 | 36 |
| | | MB | 17.3 | 0.8 | 28.0 | 20 |
| Hill#2 | Upper | NT | 13.7 | 4.4 | 16.0 | 90 |
| | | MB | 12.9 | 5.2 | 23.0 | 94 |
| | Lower | NT | 8.1 | 10.0 | 3.0 | 60 |
| | | MB | 9.0 | 9.1 | 7.0 | 50 |
| Hill#3 | Lower | NT | 18.0 | 0.1 | 12.0 | 80 |
| | | MB | 17.9 | 0.2 | 17.0 | 40 |
| | Upper | NT | 18.1 | <0.11 | 6.0 | 80 |
| | | MB | 17.9 | 0.2 | 15.0 | 67 |
| Average | | NT | $12.0^{a}$ (4.8) | $5.1^{a}$ (4.4) | $8.8^{a*}$ (4.6) | $78^{a}$ (28) |
| | | MB | $14.4^{a}$ (3.8) | $3.7^{a}$ (3.8) | $17.7^{b*}$ (7.2) | $55^{a}$ (25) |

Values in each column with different letters are significantly different at (1) 0.05 or (2) *0.025 probability level

4.1.4 Summary of Measurements at D. Lobb's

The summaries of the average hydraulic properties for each slope position and sampling date are given in Tables 29 to 32. An overall summary of the field averaged values for each sampling date are given in Table 33.

The data in Table 33 clearly show the consistent nature of the measurement over the three sampling dates. The long term no-till treatment is characterized by:

1) higher bulk density
2) lower total porosity
3) lower macroporosity
4) shorter time to ponding
5) lower matric flux potential
6) lower field saturated hydraulic conductivity
7) lower saturated hydraulic conductivity
8) higher runoff (lower infiltration rates)

compared to the long term moldboard plough treatment. These effects were consistent across all sampling times and were <u>not</u> dependent on the time of sampling.

Table 29: Comparison of average $K_{fs}$ values from the GPI for D. Lobb 1988-89.

| Site/Slope | | Texture | Field Saturated Hydraulic Conductivity ($m \cdot s^{-1} x 10^{-5}$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fall 1988 | | April 1989 | | June 1989 | |
| | | | MB | NT-8 | MB | NT-9 | MB | NT-9 |
| Hill 1 | Lower | fSL | 6.7 | 1.80 | 1.34 | 0.69 | 3.83 | 3.79 |
| | Upper | L | 13.60 | 2.82 | 2.35 | 1.46 | 1.47 | 1.08 |
| Hill 2 | Lower | SiCL | 4.82 | 0.21 | 1.24 | 0.105 | 10.8 | 1.76 |
| | Upper | SiCL | 14.70 | 0.42 | 5.50 | 1.28 | 5.39 | 0.41 |
| Hill 3 | Lower | CL | 8.50 | 1.73 | - | - | - | - |
| | Upper | CL | - | - | - | - | 1.01 | 1.56 |
| Overall Average[1] | | | $9.14^{a}$ | $1.26^{c}$ | $2.84^{b}$ | $0.91^{c}$ | $4.5^{b}$ | $1.72^{c}$ |
| S.D. | | | 5.03 | 1.53 | 3.31 | 1.61 | 7.29 | 1.82 |

[1]Values in each row with different letters are significantly different at 0.01 probability level

Table 30. Comparison of tillage effects on average matric flux potential at D. Lobb for three sampling periods 1988-89.

| Site/Slope/Tillage | | | $\phi_m$ ($m^2 \cdot s^{-1} \times 10^{-6}$) | | | Initial $\theta_v$ (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fall 1988 | April 1989 | June 1989 | Fall 1988 | April 1989 | June 1989 |
| Hill 1 | Lower | MB | 2.90 | 0.91 | 5.2 | 27.8 | 24.0 | 21.1 |
| | | NT | 0.70 | 1.22 | 4.6 | 44.9 | 27.8 | 21.6 |
| | Upper | MB | 5.06 | 1.42 | 2.9 | 38.9 | 28.6 | 27.4 |
| | | NT | 0.77 | 1.08 | 0.89 | 48.8 | 27.8 | 26.0 |
| Hill 2 | Lower | MB | 21.1 | 1.02 | 12.0 | 42.8 | 31.8 | 28.5 |
| | | NT | 0.1 | 0.07 | 1.17 | 48.3 | 30.4 | 26.1 |
| | Upper | MB | 9.00 | 5.65 | 3.7 | 39.8 | 29.6 | 33.9 |
| | | NT | 0.16 | 2.06 | 0.25 | 46.2 | 32.5 | 40.2 |
| Overall Avg. | | MB | 9.51(8.12)$^{a}$ | 2.68(4.22)$^{a}$ | 5.43(7.7)$^{a}$ | 37.3(6.6)$^{a}$ | 28.0(3.3)$^{b*}$ | 27.7(4.7)$^{b**}$ |
| | | NT | 0.42(.35)$^{a}$ | 1.14(1.73)$^{a}$ | 1.79(2.3)$^{a}$ | 47.0(1.82)$^{a}$ | 29.6(2.6)$^{b***}$ | 24.6(2.8)$^{b***}$ |

Values for each soil parameter with different values are significantly different at: (1) * 0.025 probability level (2) ** 0.05 probability level, (3) *** 0.01 probability level.

Table 31. Comparison of tillage effects on average predicted time to ponding for D. Lobb 1988-1989.

| Site/Slope/Tillage | | | Rainfall Intensity LOW 1988 | LOW April 1989 | LOW June 1989 | HIGH 1988 | HIGH April 1989 | HIGH June 1989 |
|---|---|---|---|---|---|---|---|---|
| Hill 1 | Lower | MB | 2256 | 632 | 6888 | 133 | 43 | 526 |
| | | NT | 182 | 574 | 5704 | 11 | 39 | 337 |
| | Upper | MB | 2800 | 1075 | 2168 | 165 | 73 | 128 |
| | | NT | 71 | 565 | 633 | 4 | 38 | 37 |
| Hill 2 | Lower | MB | 5600 | 521 | 743 | 342 | 35 | 44 |
| | | NT | 6 | 22 | 1858 | 1 | 2 | 116 |
| | Upper | MB | 3360 | 3593 | 908 | 200 | 246 | 53 |
| | | NT | 31 | 1263 | 1 | 86 | 86 | <1 |
| | Average | MB | $3554^{a}$(1564) | $1567^{a}$(1455) | $3176^{a}$(3860) | $210^{a}$(92) | $92^{a}$(86) | $187^{a}$(229) |
| | | NT | $72^{a}$(78) | $716^{a}$(587) | $2074^{b}$(2554) | $4^{a}$(5) | $42^{a}$(35) | $123^{b}$(151) |

(standard deviation)

Values in the same row with different letters are significantly different at 0.05 probability level.

Table 32: Comparison of average porosity indices for three sampling periods at D. Lobb, Clinton, Ontario, 1988-89.

| Site/Slope/Tillage | | | Bulk Density ($g \cdot cm^{-3}$) 1988 | Bulk Density ($g \cdot cm^{-3}$) April 89 | Total Porosity ($m^3 \cdot m^{-3}$) 1988 | Total Porosity ($m^3 \cdot m^{-3}$) April 89 | Macroporosity ($m^3 \cdot m^{-3}$) 1988 | Macroporosity ($m^3 \cdot m^{-3}$) April 89 | Relative Macroporosity (%) 1988 | Relative Macroporosity (%) April 89 |
|---|---|---|---|---|---|---|---|---|---|---|
| Hill 1 | Lower | MB | 1.44 | 1.39 | 0.47 | 0.48 | 0.08 | 0.06 | 17 | 13.4 |
| | | NT | 1.58 | 1.45 | 0.43 | 0.46 | 0.08 | 0.05 | 18 | 10.0 |
| | Upper | MB | 1.48 | 1.48 | 0.46 | 0.45 | 0.08 | 0.08 | 18 | 16.3 |
| | | NT | 1.61 | 1.64 | 0.41 | 0.42 | 0.06 | 0.05 | 14 | 12.0 |
| Hill 2 | Lower | MB | 1.31 | 1.37 | 0.52 | 0.52 | 0.13 | 0.12 | 25 | 22.0 |
| | | NT | 1.54 | 1.54 | 0.43 | 0.44 | 0.06 | 0.05 | 15 | 10.0 |
| | Upper | MB | 1.43 | 1.36 | 0.47 | 0.52 | 0.06 | 0.12 | 13 | 22.1 |
| | | NT | 1.50 | 1.66 | 0.47 | 0.47 | 0.05 | 0.05 | 11 | 8.4 |
| Average[1] | | MB | $1.42^{a**}$ | $1.40^{a**}$ | $.476^{a**}$ | $.49^{a**}$ | $.086^{a**}$ | $.093^{a**}$ | $17.5^{a**}$ | $18.4a^{*}$ |
| | | NT | $1.56^{a**}$ | $1.57^{a**}$ | $.432^{a**}$ | $.45^{a**}$ | $.063^{a***}$ | $.049^{b**}$ | $14.6^{a***}$ | $10.3^{b**}$ |

[1]Values for each soil parameter with different letters are significantly different at:(1) *0.05 probability level (2) ** 0.01 probability level

Table 33: Summary of hydraulic properties at D. Lobb's site for all measurement dates.

| Hydraulic Property | Tillage | Oct. 1988 | April 1989* | June 1989 |
|---|---|---|---|---|
| $K_{fs}$ ($ms^{-1}x10^{-5}$) | MB | 9.14 | 2.84 | 4.50 |
| | NT | 1.26 | 0.91 | 1.72 |
| $K_{sat}$ ($ms^{-1}x10^{-5}$) | MB | 9.89 | 60.55 | N/A |
| | NT | 0.94 | 18.80 | N/A |
| $\phi_m$ ($m^2sx10^{-6}$) | MB | 4.04 | 2.68 | 5.43 |
| | NT | 0.22 | 1.14 | 1.79 |
| $\alpha^*$ ($m^{-1}$) | MB | 24.5 | 10.6 | 8.3 |
| | NT | 42.7 | 7.8 | 9.6 |
| $T_p$ (s) | MB | 210 | 92 | 187 |
| | NT | 4 | 42 | 123 |
| $\rho_b$ | MB | 1.40 | 1.40 | N/A |
| | NT | 1.54 | 1.57 | N/A |
| $\theta_{sat}$ | MB | 0.486 | 0.494 | N/A |
| | NT | 0.449 | 0.449 | N/A |
| $\theta_{macro}$ | MB | 0.097 | 0.093 | N/A |
| | NT | 0.063 | 0.048 | N/A |

## 4.2 Surface Hydraulic Properties

### 4.2.1 Site Description - D. Ghent T-2000 Site, Mt. Forest Ontario

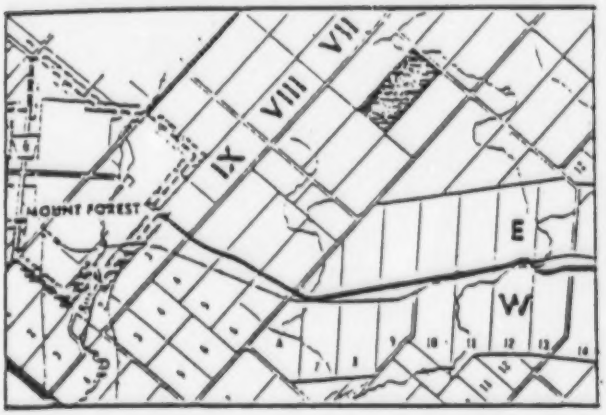
A second T-2000 site was investigated where surface hydraulic properties were measured with the GPI in conjunction with rainfall simulation experiments. The farm of D. Ghent is located in Wellington County, Arthur Township, Lot 5, Concession 7 near Mt. Forest, Ontario. The site was chosen because it provided a minimum till ( i.e fall chisel plough) versus no-till comparison on a medium textured soil (Perth silt loam). In 1988 clover was underseeded to the winter wheat crop. In 1989 the clover was left for a hay crop and was mowed for the rainfall simulation trials. All field measurements were done in October, 1989. Afterwards, 4-5 GPI measurements were taken on each paired treatment plot at two slope positions. Figures 5 and 6 (from Aspinall et al., 1987) show the location and layout of the site respectively. Each runoff plot measured 1.6m x 4.0m and was located near T-2000 Benchmarks 2 and 4.

### 4.2.2 Results and Discussion

A summary of the data collected for each individual replication of the GPI is given in Appendix 3a along with the calculated hydraulic parameters, $K_{fs}$ and $\phi_m$. The soil porosity indices measured in the laboratory from intact cores, including bulk density, soil water content vs. matric potential, and the calculated pore size distributions are given in Appendix 3b.

The measured values from each replication of the GPI are given in Table 34 and the data are summarized in Table 35. The average $K_{fs}$ for the minimum till at the upper slope position was 2x higher than that measured in the no-till plot. Similarly, the average $K_{fs}$ at the lower slope position was 6x higher in the minimum till as compared to the no-till treatment. Both

"FARM LOCATION"




David Ghent
Wellington County
Arthur Township
Lot 5, Concession 7
(519) 323-1448

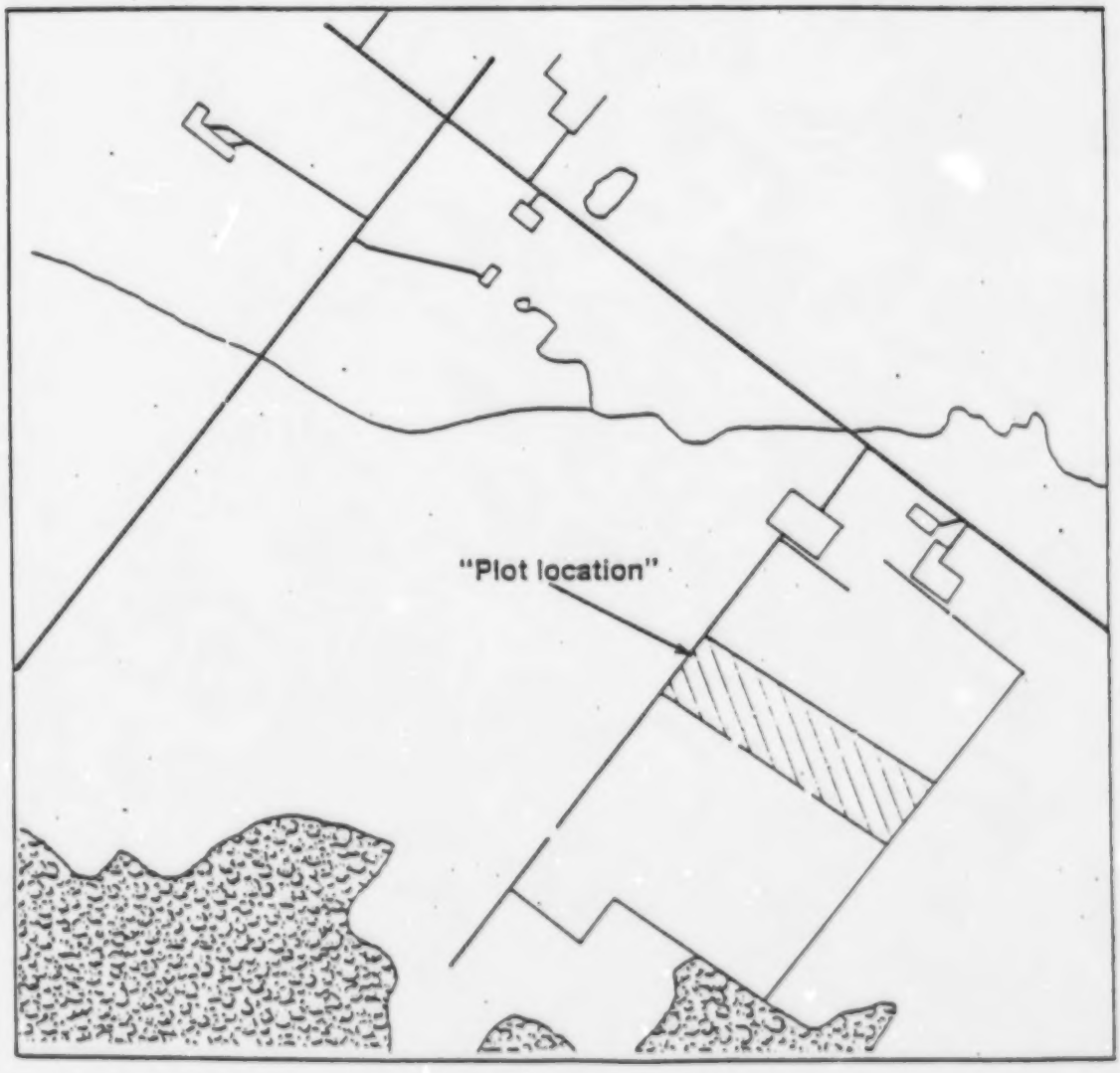



Fig. 5 Site location - D. Ghent T2000 Site, Mt. Forest Ontario

# GHENT — Detailed Plot Description

All distances in meters

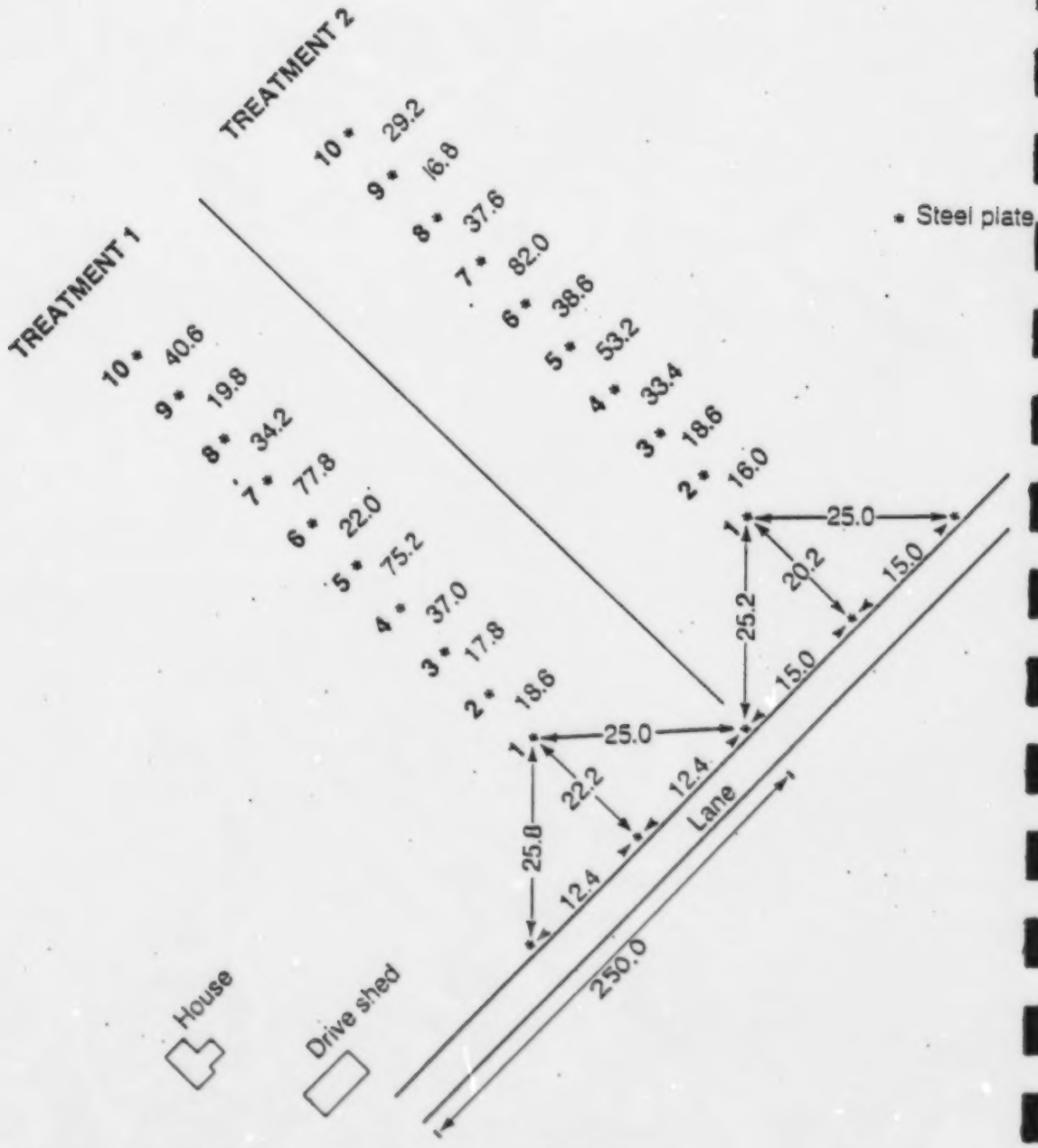



Fig. 6 Detailed plot layout - D. Ghent T-2000 Site

Table 34: Measured $K_{fs}$ from pressure infiltrometer for D. Ghent (T-2000)

| Site/Slope/Tillage | | Field Saturated Hydraulic Conductivity $K_{fs}$ ($m \cdot s^{-1}$ $x10^{-6}$) Replication Number 1 | 2 | 3 | 4 | 5 | Geometric X | Geometric S | Arithmetic $\bar{X}$ | Arithmetic S |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 Upper | MIN | 35.1 | 13.0 | 19.5 | 6.35 | 6.4 | 12.96 | 20.8 | 16.08 | 11.93 |
| | NT | 1.2 | 15.9 | 4.0 | 10.24 | 0.6 | 3.44 | 0.60 | 6.40 | 6.55 |
| 2 Lower | MIN | 34.2 | 70.3 | 18.4 | 137.6 | 180.5 | 64.3 | 41.3 | 88.19 | 69.0 |
| | NT | 71.1 | 0.03 | 0.92 | 0.22 | 0.34 | 0.67 | 12.5 | 14.5 | 31.6 |

Table 35: Summary of average field saturated hydraulic conductivity measured with the pressure infiltrometer (D. Ghent)

| Site/Slope | Field Saturated Hydraulic Conductivity $K_{fs}$ ($m \cdot s^{-1}$ $x10^{-6}$) MIN | No Till |
|---|---|---|
| 1 Upper | 16.1 | 6.4 |
| 2 Lower | 88.2 | 14.5 |
| Overall Average | 52.1[a1] | 10.45[b] |
| S.D. | 60.2 | 21.96 |

(standard deviation)
[1]Values in the same row with different letters are significantly different at 0.05 probability level

sites exhibited a high coefficient of variation so that when the overall averages (both slope positions) were compared, $K_{fs}$ in the minimum till was significantly higher (0.05 probability level) than that found in the no-till treatment. The spatial variability of $K_{fs}$ was also 3x higher in the minimum till. The relative variation given by the coefficient of variation was higher in the NT plot. The Ksat data (Table 36) were inconsistent with the $K_{fs}$ data (the only site where this is the case). The Ksat data indicate a higher Ksat in the no-till compared to minimum till (though the difference is not significant). While this certainly could be true, the other hydraulic properties from the cores (porosity, bulk density, macroporosity, etc.)all suggest that the Ksat should be lower. The presence of one or two large roots in the cores (the site was in clover since the previous fall) may have skewed the Ksat measurements.

The runoff data for the site are given in Table 37. The data are consistent with the measured $K_{fs}$ values with much higher runoff rates in the no-till compared to the minimum till. In addition, the matric flux potential (Table 38) was 5x lower in the no-till (significant at the 0.025 probability level). This resulted in a considerably shorter predicted time to ponding. Table 39 contains the measured Tp values for each replication and the data are summarized in Table 40. The data are consistent with the measured $K_{fs}$ and runoff values, confirming that the no-till had a significantly lower Tp than the minimum till treatment (significant at 0.01 probability level).

The differences in average $K_{fs}$ and the measured effects on soil loss can be explained by the porosity indices given in Table 41 and 42. The NT plot had an average bulk density that was significantly higher compared to the minimum till treatment, and this was reflected in a significantly lower

Table 36: Comparison of $K_{fs}$ from pressure infiltrometer and $K_{sat}$ from undisturbed cores (D. Ghent - T-2000)

| Site/Slope/Tillage | | Pressure Infiltrometer (Y) ($m \cdot s^{-1} \times 10^{-5}$) | Ksat (X) ($m \cdot s^{-1} \times 10^{-5}$) |
|---|---|---|---|
| 1 Upper | MIN | 1.61 | 15.89 |
| | NT | 0.64 | 24.2 |
| 2 Lower | MIN | 8.82 | 7.8 |
| | NT | 1.45 | 12.92 |
| Average | Min | 5.21[a1] | 11.8[a] |
| | NT | 1.05[a] | 18.6[a] |

[1]Values with different letters are significantly different at 0.05 probability level

Table 37. Runoff data from rainfall simulation trails at D. Ghent (1989).

| Site/Slope/Tillage | | Time to Ponding (S) | Water Runoff (cm) | Steady State Runoff Rate (cm/hr) | Steady State Infiltration (cm/hr) | Soil Loss (+/ha) |
|---|---|---|---|---|---|---|
| 1 Upper | MIN | 150 | 0.4 | 2.3 | 10.2 | 0.03 |
| | NT | 120 | 1.2 | 3.6 | 8.9 | 0.03 |
| 2 Lower | MIN | 600 | 0.4 | 0.5 | 12.1 | 0.45 |
| | NT | 90 | 1.0 | 6.4 | 6.1 | 0.03 |
| Average | MIN | 375 | 0.4 | 1.4 | 11.4 | 0.24 |
| | NT | 105 | 1.1 | 5.0 | 7.5 | 0.03 |

Table 38: Summary of tillage effects on average Matric Flux Potential $\phi m$ measurements for D. Ghent (T-2000).

| Site | Slope | Matric Flux Potential ($m^2 \cdot s^{-1} \times 10^{-6}$) | | Initial Soil Water Content ($m^3 \cdot m^{-3}$) | |
|---|---|---|---|---|---|
| | | MIN | NT | MIN | NT |
| 1 | Upper | 0.85 | 0.59 | 32.7 | 32.0 |
| 2 | Lower | 7.49 | 1.21 | 33.6 | 31.6 |
| Overall | Average[1] | 4.17[a] | 0.80[b] | 33.2[a] | 31.8[a] |
| | S.D. | 4.58 | 1.85 | 2.66 | 0.36 |

[1]Values for each soil parameter with different letters are significantly different at 0.025 probability level

Table 39: Measured data for calculation of predicted time to ponding for D. Ghent (T-2000)

| Site | Mgt. | Rep. | Soil Water Content $\theta i$ | $\theta f$ ($m^3 \cdot m^{-3}$) | $\Delta\theta$ | $\phi m$ ($m^2 \cdot s^{-1} \times 10^{-6}$) | Calculated Time to Ponding Low Intensity | High Intensity |
|---|---|---|---|---|---|---|---|---|
| 1 | MIN | 1 | .324 | .402 | .078 | 2.16 | 1312 | 78 |
| | | 2 | .305 | .418 | .113 | 0.619 | 545 | 32 |
| | | 3 | .339 | .418 | .079 | 0.928 | 571 | 34 |
| | | 4 | .339 | .406 | .067 | 0.302 | 157 | 9 |
| | | 5 | - | - | - | 0.242 | - | - |
| | X | | .327 | .411 | .084 | 0.85 | 646 | 38 |
| | NT | 1 | .319 | .380 | .061 | 0.0769 | 36 | 2 |
| | | 2 | .324 | .389 | .065 | 1.56 | 790 | 47 |
| | | 3 | .319 | .385 | .066 | 0.136 | 70 | 4 |
| | | 4 | .319 | .398 | .079 | 1.131 | 696 | 41 |
| | | 5 | .319 | .398 | .079 | 0.0374 | 23 | 1 |
| | X | | .320 | .390 | .070 | 0.588 | 323 | 19 |
| 2 | MIN | 1 | .315 | .406 | .091 | 2.63 | 1864 | 110 |
| | | 2 | .315 | .426 | .111 | 5.41 | 4677 | 277 |
| | | 3 | .371 | .414 | .043 | 9.70 | 3248 | 192 |
| | | 4 | .376 | .426 | .050 | 5.80 | 2258 | 134 |
| | | 5 | .305 | .389 | .084 | 13.89 | 9087 | 538 |
| | X | | .336 | .412 | .076 | 7.49 | 4227 | 250 |
| | NT | 1 | .319 | .393 | .074 | 5.92 | 3412 | 202 |
| | | 2 | .319 | .398 | .079 | 0.0024 | 1 | < 1 |
| | | 3 | .319 | .406 | .087 | 0.0769 | 52 | 3 |
| | | 4 | .310 | .389 | .079 | 0.0182 | 11 | < 1 |
| | | 5 | .315 | .362 | .047 | 0.0280 | 10 | < 1 |
| | X | | .316 | .390 | .073 | 1.21 | 697 | 41 |

Low Intensity Rainfall Rate = 0.68 $mm \cdot min^{-1}$
High Intensity Rainfall Rate = 2.8 $mm \cdot min^{-1}$

Table 40: Comparison of predicted Tp for tillage treatments at D. Ghent (T-2000)

| Site/Slope | Rain Intensity | Calculated Time to Ponding Tp(s) MIN Till | No Till |
|---|---|---|---|
| 1 Upper | LOW | 646 | 323 |
| | HIGH | 38 | 19 |
| 2 Lower | LOW | 4227 | 697 |
| | HIGH | 250 | 41 |
| Overall Average | Low | $2436^{a1}$ (2532) | $510^{b}$ (264) |
| | High | $144^{a}$ (150) | $30^{b}$ (15) |

(standard deviation)
[1]Values in same row with different letters are significantly different at 0.01 probability level

Table 41: Summary of porosity indices from undisturbed cores for D. Ghent (T-2000)

| Site/Slope/Rep | | Bulk Density ($g \cdot cm^{-3}$) | | Total Porosity ($m^3 \cdot m^{-3}$) | | Macroporosity ($m^3 \cdot m^{-3}$) | | Relative Macroporosity (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | MIN | NT | MIN | NT | MIN | NT | MIN | NT |
| 1 Upper | 1 | 1.33 | 1.36 | 0.519 | 0.532 | 0.142 | 0.097 | 27.4 | 18.2 |
| | 2 | 1.36 | 1.33 | 0.535 | 0.532 | 0.131 | 0.111 | 24.5 | 20.9 |
| | 3 | 1.29 | 1.32 | 0.559 | 0.530 | 0.107 | 0.098 | 19.1 | 18.5 |
| | 4 | 1.27 | - | 0.605 | - | 0.163 | - | 26.9 | - |
| | 5 | 1.35 | 1.44 | 0.571 | 0.538 | 0.126 | 0.114 | 22.1 | 21.2 |
| X | | 1.32 | 1.36 | 0.558 | 0.533 | 0.134 | 0.105 | 24.0 | 19.7 |
| 2 Lower | 1 | 1.32 | 1.46 | 0.538 | 0.520 | 0.012 | 0.089 | 20.8 | 17.1 |
| | 2 | 1.34 | 1.46 | 0.521 | 0.511 | 0.154 | 0.109 | 29.5 | 21.3 |
| | 3 | - | 1.39 | - | 0.449 | - | 0.076 | - | 16.9 |
| | 4 | 1.35 | 1.35 | 0.524 | 0.515 | 0.091 | 0.111 | 17.4 | 21.5 |
| | 5 | 1.27 | - | 0.599 | - | 0.178 | - | 29.7 | - |
| $\bar{X}$ | | 1.32 | 1.41 | 0.545 | 0.499 | 0.134 | 0.096 | 24.3 | 19.2 |

Table 42: Summary of average treatment effects in porosity indices from undisturbed cores for D. Ghent (T-2000)

| Site | Slope | Bulk Density ($g \cdot cm^{-3}$) | | Total Porosity ($m^3 \cdot m^{-3}$) | | Macroporosity ($m^3 \cdot m^{-3}$) | | Relative Macroporosity ($m^3 \cdot m^{-3}$) | |
|---|---|---|---|---|---|---|---|---|---|
| | | MIN | NT | MIN | NT | MIN | NT | MIN | NT |
| 1 | Upper | 1.32 | 1.36 | 0.558 | 0.533 | 0.134 | 0.105 | 24.0 | 19.7 |
| 2 | Lower | 1.32 | 1.41 | 0.545 | 0.499 | 0.134 | 0.096 | 24.3 | 19.2 |
| Overall | Average | 1.32[a] | 1.38[b] | 0.552[a] | 0.516[b] | 0.123[a] | 0.101[b] | 24[a] | 19[b] |
| | S.D. | 0.03 | 0.06 | 0.03 | 0.03 | 0.05 | 0.01 | 4.55 | 1.91 |

Values in the same row with different letters are significantly different at 0.01 probability level

total porosity. This was attributed to a reduction in macroporosity and relative macroporosity (significant at 0.01 level). The decreased macroporosity would account for the decreased $K_{fs}$, the lowering of the steady state infiltration rate, and increased runoff rates in the no-till seen in Table 37. These results are consistent with the effects of no-till at D. Lobb's T-2000 site.

4.2.3 Site Description - F. Anthony T-2000 Site, Halton Hills, Ontario

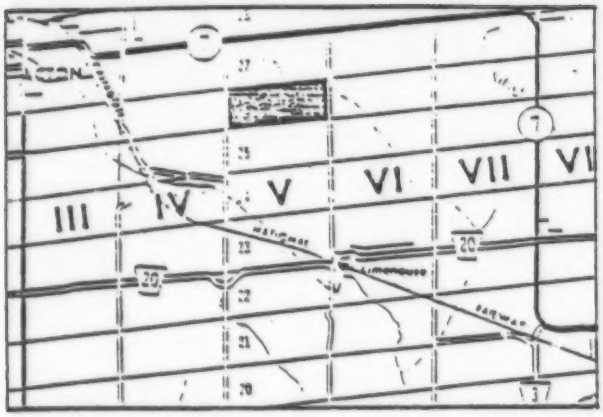
A third T-2000 site was chosen to provide a comparison of minimum till versus moldboard plough. The farm of F. Anthony is located in the Regional Municipality of Halton, Town of Halton Hills, Lot 26, Concession V, just to the west of the Town of Acton (Figures 7 and 8). The soil texture is loam (48% sand, 39% silt and 13% clay). Paired sites were selected at three slope positions which coincide with T-2000 Benchmark location 4, 5 and 9. Each plot was 1.6m x 4.0m for the rainfall simulation trials and 4-5 readings were taken with the GPI in each plot. Undisturbed cores were also taken to measure soil porosity indices.

4.2.4 Results and Discussion

A summary of the data collected for each individual replication if the GPI is given in Appendix 4a. along with the measured porosity indices for all undisturbed cores taken in the plots (Appendix 4b.). The measured $K_{fs}$ data from the GPI are summarized in Table 43. A high degree of variability exists within each slope position, though the results are similar to other field trials and again are probably representative of the natural variability. The overall averages for both treatments showed that MB had a significantly higher average $K_{fs}$ than the SS treatment (0.05 probability level).

A comparison of $K_{fs}$ from the GPI and Ksat from the undisturbed cores (Table 44) shows a correlation coefficient r = 0.54. The higher average Ksat values are again expected, since the field value is more affected by pore continuity than the undisturbed core where macropores would be vented at the bottom thus leading to higher K values. As well the core method measures the full saturated K value while the GPI measures a field

"FARM LOCATION"




**Frank Anthony**
Regional Municipality of Halton
Town of Halton Hills
Lot 26, Concession V
(519) 853-0018

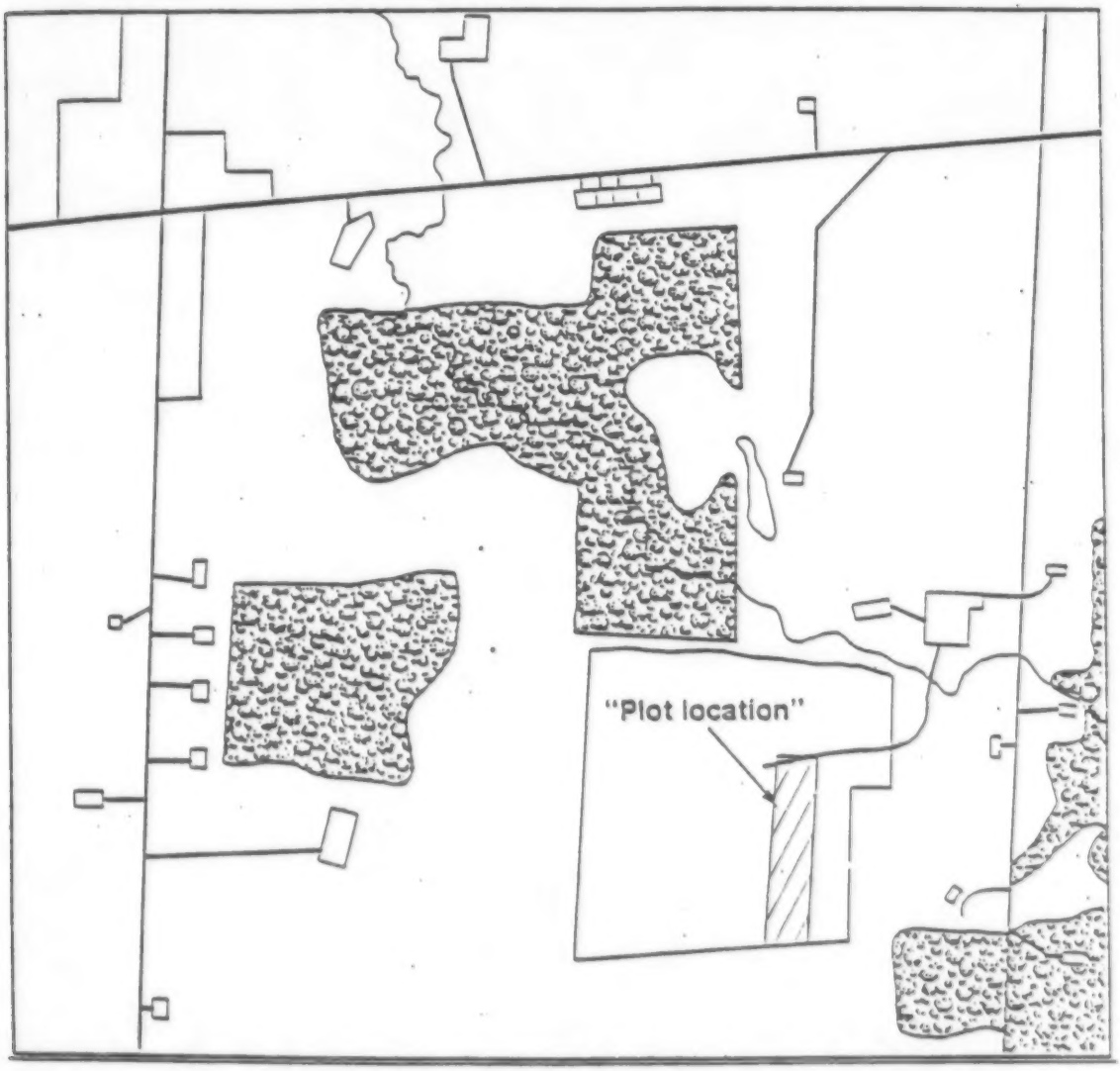



Fig. 7 Site location - F. Anthony T-2000 Site, Halton Hills Ontario

# ANTHONY — Detailed Plot Description

All distances in meters

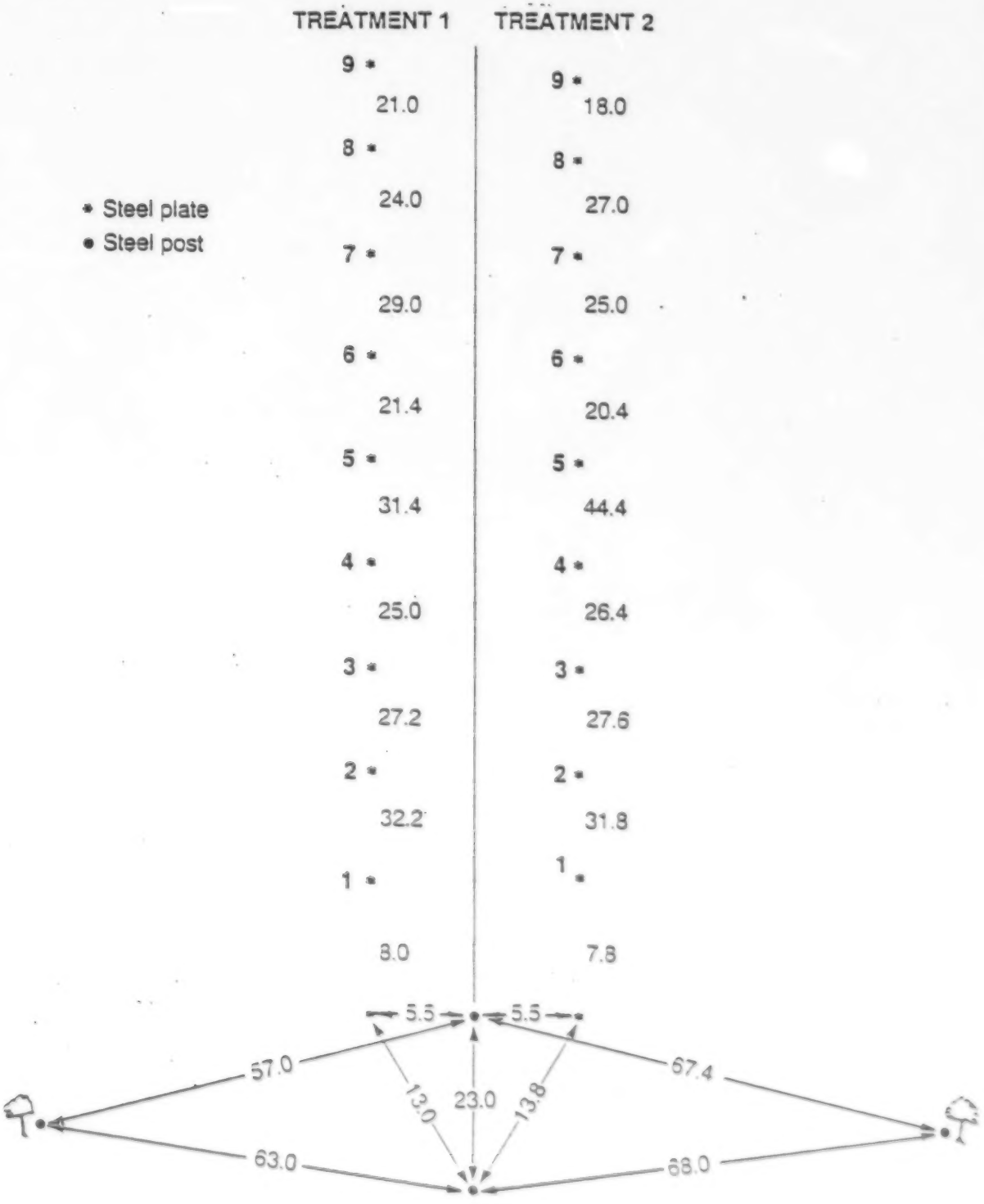



Fig. 8 Detailed plot layout - F. Anthony T-2000 Site, Halton Hills Ontario

Table 43: Summary of saturated hydraulic conductivity from pressure infiltrometer for F. Anthony (T-2000).

| Site/Slope/ Tillage | | | Field saturated $K_{fs}$ ($m \cdot s^{-1} \times 10^{-5}$) Replication Number | | | | | Geometric | | Arithmetic | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | $\bar{X}$ | S | $\bar{X}$ | S |
| Hill 1 | Lower | MB | 6.35 | 4.63 | 0.575 | 11.45 | 7.98 | 4.34 | 3.25 | 6.2 | 4.03 |
| | | SS | 16.84 | 1.75 | 8.28 | 7.08 | 8.21 | 6.77 | 2.29 | 8.43 | 5.41 |
| | Upper | MB | 1.41 | 0.945 | 0.526 | 11.41 | 21.34 | 2.79 | 5.07 | 7.13 | 9.15 |
| | | SS | 1.24 | 0.314 | 0.465 | 0.044 | 0.074 | 0.22 | 3.91 | 0.43 | 0.49 |
| Hill 2 | Lower | MB | 24.1 | 10.31 | 8.54 | 7.64 | 7.08 | 10.28 | 1.64 | 11.53 | 7.13 |
| | | SS | 16.41 | 5.49 | 13.78 | 9.03 | 7.55 | 9.67 | 1.56 | 10.45 | 4.52 |
| Overall Average | | MB | 8.28[a] (6.99) | | | | | | | | |
| | | SS | 6.43[b] (5.86) | | | | | | | | |

(standard deviation)
Values with different letters are significantly different at 0.05 probability level

Table 44: Comparison of average hydraulic properties from GPI (Kfs) and undisturbed cores (Ksat) for F. Anthony (T-2000).

| Site/Slope | | Field Saturated $K_{fs}$ ($m \cdot s^{-1} \times 10^{-5}$) | | | |
|---|---|---|---|---|---|
| | | MB | | SS | |
| | | Kfs (Y) | Ksat (X) | Kfs (Y) | Ksat (X) |
| Hill 1 | Lower | 6.2 | 6.58 | 8.43 | 3.24 |
| | Upper | 7.13 | 13.43 | 0.43 | 2.38 |
| Hill 2 | Lower | 11.53 | 14.83 | 10.45 | 51.43 |
| Overall Average | | 8.29 | 11.61 | 6.44 | 19.02 |
| (S.D.) | | (6.99) | (11.61) | (5.86) | (42.6) |

Correlation of Y on X  r = 0.54
n = 6

saturated K value.

The measured runoff data from the Anthony site for the high intensity storm are given in Table 45. The moldboard infiltration rates are only marginally higher than the soil save treatment. The total soil and phosphorus loss measured from the rainfall simulation experiment were also higher in the soil-save compared to the moldboard treatment. The similarity in runoff rates is consistent with the detailed measurements of hydraulic properties found with the pressure infiltrometer. The overall effect of tillage on average hydraulic properties was therefore minimal.

The measured matric flux potential $\phi_m$ was also only slightly lower in the soil save treatment (Table 46). Table 47 shows the calculated values for Tp based on the measured GPI values. The data are summarized in Table 48 and indicated the predicted time to ponding is slightly lower in the soil-save treatment compared to the moldboard, though the difference is not significant (0.05 probability level). This data was consistent with the observed values from the rainfall simulation trials with measured Tp slightly lower in the soil-save treatment.

The individual measured porosity indices for each core are found in Table 49 and the data are summarized in Table 50. Little difference was found between treatments at this site. The soil save treatment had a marginally lower average bulk density (1.27 vs 1.29 $g \cdot cm^{-3}$) but the difference was not significant at the 0.05 probability level. Both treatments had a similar average total porosity. The slightly lower macroporosity in the soil save treatment (0.105 vs. 0.12 in the MB) and subsequent lower relative macroporosity may explain the slightly lower average $K_{fs}$ values in the soil save plots. The core data are consistent with

Table 45: Runoff measurements on Anthony simulation (2.8 mm $min^{-1}$) in Sept., 1989.

| Site/Slope/Tillage | | Time to Ponding (sec) | Water runoff (cm) | Steady-state runoff rate (cm/hr) | Steady-state infiltration (cm/hr) | Soil loss (t/ha) | Total Phosphorus Loss(kg/ha) |
|---|---|---|---|---|---|---|---|
| 4 Upper | min. | 184 | 1.1 | 5.1 | 7.4 | 0.36 | 1.71 |
| | MB | 240 | 1.3 | 6.0 | 6.5 | 0.61 | 1.55 |
| 5 Mid | min | 180 | 1.0 | 4.5 | 8.0 | 0.77 | 2.59 |
| | MB | 195 | 0.8 | 3.8 | 8.7 | 0.61 | 1.83 |
| 9 Lower | min | | 1.1 | 2.8 | 9.7 | 0.42 | 1.01 |
| | MB | 60 | 0.6 | 1.8 | 10.7 | 0.15 | 0.42 |
| Avg | min | 182[a] | 1.06[a] | 4.1[a] | 8.4[a] | 0.52[a] | 1.77[a] |
| | MB | 165[a] | 0.90[a] | 3.9[a] | 8.6[a] | 0.46[a] | 1.27[a] |

Values in same column with different letters are significantly different at 0.05 probability level

Table 46: Summary of tillage effects on average Matric Flux Potential $\phi m$ measurements for F. Anthony (T-2000)

| | | Matric Flux Potential ($m^2 \cdot s^{-1} \times 10^{-6}$) | | Initial Soil Water Content ($m^3 \cdot m^{-3}$) | |
|---|---|---|---|---|---|
| | | MB | SS | MB | SS |
| Hill 1 | Lower | 2.51 | 5.64 | - | - |
| | Upper | 3.76 | 0.53 | 22.5 | 27.8 |
| Hill 2 | Lower | 7.00 | 3.29 | 25.3 | 23.4 |
| Overall Average | | 4.42[a] | 3.15[a] | 23.9[a] | 25.6[a] |
| S.D. | | 4.2 | 3.4 | 3.18 | 3.24 |

Values for each soil parameter with different letters are significantly different at 0.05 probability level.

Table 47: Measured data for calculation of predicted Tp for F. Anthony

| Site/Slope/Mgt. | Rep. | θi | θv ($m^3 \cdot m^{-3}$) | Δθ | ϕm ($m^2 \cdot s^{-1} x 10^{-6}$) | Calculated Tp(s) Low Intensity | High |
|---|---|---|---|---|---|---|---|
| Hill 1 Upper MB | 1 | .232 | .385 | .153 | 0.930 | 1108 | 66 |
| | 2 | .242 | .358 | .116 | 0.525 | 474 | 28 |
| | 3 | .179 | .305 | .126 | 0.292 | 286 | 17 |
| | 4 | .242 | .353 | .111 | 5.23 | 4521 | 267 |
| | 5 | .232 | .353 | .121 | 11.85 | 11167 | 661 |
| $\bar{X}$ | | .225 | .351 | .125 | 3.76 | 3511 | 208 |
| SS | 1 | .284 | .367 | .083 | 1.55 | 1002 | 59 |
| | 2 | .279 | .334 | .055 | 0.176 | 75 | 4 |
| | 3 | .269 | .334 | .065 | 0.581 | 294 | 17 |
| | 4 | .279 | .349 | .069 | 0.219 | 118 | 7 |
| | 5 | .279 | .380 | .101 | 0.115 | 90 | 5 |
| $\bar{X}$ | | .278 | .353 | .075 | 0.528 | 316 | 18 |
| Hill 2 Lower MB | 1 | .242 | .362 | .120 | 12.68 | 11850 | 701 |
| | 2 | .216 | .376 | .160 | 10.76 | 13408 | 793 |
| | 3 | .299 | .398 | .099 | 2.72 | 2097 | 124 |
| | 4 | .232 | .376 | .144 | 4.02 | 4508 | 267 |
| | 5 | .274 | .389 | .115 | 4.80 | 4299 | 254 |
| $\bar{X}$ | | .253 | .380 | .128 | 7.00 | 7232 | 428 |
| SS | 1 | .179 | .367 | .188 | 5.89 | 8623 | 510 |
| | 2 | .242 | .344 | .102 | 1.66 | 1319 | 78 |
| | 3 | .232 | .376 | .144 | 4.17 | 4677 | 277 |
| | 4 | .269 | .367 | .098 | 2.46 | 1878 | 111 |
| | 5 | .248 | .367 | .119 | 2.29 | 2122 | 126 |
| $\bar{X}$ | | .234 | .364 | .130 | 3.29 | 3724 | 220 |

Low Intensity Rainfall Rate = 0.68 $mm \cdot min^{-1}$
High Intensity Rainfall Rate = 2.8 $mm \cdot min^{-1}$

Table 48: Comparison of predicted Tp for tillage treatments at F. Anthony (T-2000)

| Site/slope | | Rain Intensity | Calculated time to ponding Tp (s) Moldboard | Soil Saver |
|---|---|---|---|---|
| Hill 1 | Lower | Low | - | - |
| | | High | - | - |
| | Upper | Low | 3511 | 316 |
| | | High | 208 | 18 |
| Hill 2 | Lower | Low | 7232 | 3724 |
| | | High | 428 | 220 |
| Overall Average | | Low | 5371[a] (2631) | 2020[a] (2410) |
| | | High | 318[a] (155) | 119[a] (143) |

(standard deviation)
Values in the same row with different letters are significantly different at 0.05 probability level

Table 49: Summary of porosity indices from undisturbed core measurements for F. Anthony T-2000

| Site/Slope/Rep | | | Bulk Density ($g \cdot cm^{-3}$) | | Total Porosity ($m^3 \cdot m^{-3}$) | | Macroporosity ($m^3 \cdot m^{-3}$) | | Relative Macroporosity (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | MB | SS | MB | SS | MB | SS | MB | SS |
| Hill 1 | Lower | 1 | 1.41 | 1.21 | 0.403 | 0.481 | 0.084 | 0.100 | 20.8 | 20.8 |
| | | 2 | 1.23 | 1.42 | 0.479 | 0.439 | 0.072 | 0.079 | 15.0 | 18.0 |
| | | 3 | 1.28 | 1.27 | 0.526 | 0.481 | 0.121 | 0.088 | 23.0 | 18.3 |
| | | 4 | 1.21 | 1.38 | 0.685 | 0.486 | 0.265 | 0.087 | 38.7 | 17.9 |
| | | 5 | 1.23 | 1.05 | 0.591 | 0.466 | 0.178 | 0.071 | 30.1 | 18.2 |
| | X | | 1.27 | 1.27 | 0.537 | 0.471 | 0.144 | 0.085 | 25.5 | 18.0 |
| | Upper | 1 | 1.35 | 1.47 | 0.472 | 0.422 | 0.076 | 0.055 | 16.1 | 13.0 |
| | | 2 | 1.37 | 1.40 | 0.490 | 0.473 | 0.096 | 0.064 | 19.6 | 13.5 |
| | | 3 | 1.44 | 1.22 | 0.366 | 0.508 | 0.104 | 0.075 | 28.4 | 14.8 |
| | | 4 | 1.39 | 1.35 | 0.469 | 0.571 | 0.127 | 0.123 | 27.1 | 21.5 |
| | | 5 | 1.18 | 1.17 | 0.446 | 0.525 | 0.068 | 0.100 | 15.2 | 19.0 |
| | X | | 1.35 | 1.32 | 0.449 | 0.500 | 0.094 | 0.083 | 21.3 | 16.4 |
| Hill 2 | Lower | 1 | 1.26 | 1.19 | 0.524 | 0.551 | 0.121 | 0.181 | 23.1 | 32.8 |
| | | 2 | 1.26 | 1.24 | 0.508 | 0.517 | 0.125 | 0.122 | 24.6 | 23.6 |
| | | 3 | 1.35 | 1.28 | 0.492 | 0.531 | 0.099 | 0.106 | 20.1 | 20.0 |
| | | 4 | 1.17 | 1.17 | 0.476 | 0.519 | 0.107 | 0.153 | 22.5 | 29.5 |
| | | 5 | 1.25 | 1.20 | 0.511 | 0.542 | 0.159 | 0.165 | 31.1 | 30.4 |
| | X | | 1.26 | 1.22 | 0.502 | 0.532 | 0.122 | 0.145 | 24.3 | 27.3 |

Table 50: Summary of average treatment effects in porosity indices from undisturbed cores for F. Anthony (T-2000)

| Site/Slope | | Bulk Density ($g \cdot cm^{-3}$) | | Total Porosity ($m^3 \cdot m^{-3}$) | | Macroporosity ($m^3 \cdot m^{-3}$) | | Relative Macroporosity (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | MB | SS | MB | SS | MB | SS | MB | SS |
| Hill 1 | Lower | 1.27 | 1.27 | 0.537 | 0.471 | 0.144 | 0.085 | 25.5 | 18.0 |
| | Upper | 1.35 | 1.32 | 0.449 | 0.500 | 0.094 | 0.083 | 21.3 | 16.4 |
| Hill 2 | Lower | 1.26 | 1.22 | 0.502 | 0.532 | 0.122 | 0.145 | 24.3 | 27.3 |
| Overall Average | | 1.29[a] | 1.27[a] | 0.496[a] | 0.501[a] | 0.120[a] | 0.105[a] | 23.7[a] | 20.7[a] |
| S.D | | 0.09 | 0.11 | 0.07 | 0.04 | 0.05 | 0.04 | 6.6 | 6.0 |

Values for each soil parameter with different letters are significantly different at 0.05 probability level

the measured steady state infiltration rates and suggests that the minimum till system resulted in a slight increase in runoff and a lower rate of infiltration into the soil matrix at the higher rainfall intensity.

## 5.0 STUDY SITES WITH ONLY AN ASSESSMENT OF SURFACE PROPERTIES

### 5.1 Elora Research Station

#### 5.1.1 Site Description

During the 1989 field season, extensive use was also made of different tillage/cropping systems. One site of particular interest are the long-term tillage trials at the Elora Research Station near Guelph. These plots were initiated by Professor J.W. Ketcheson in 1969 and are located on a Conestoga silt loam (Gleyed Grey Brown Luvisol). The plot layout and the soils at this site have been previously described by Ketcheson (1980). The tillage experiment was a randomized complete block design with four replications. Each tillage plot was 47 m x 7.6 m. Two tillage systems were used, a fall moldboard plough followed by harrowing twice in the spring, and no-till on an adjacent site. Both treatments have been in continuous corn since 1969.

#### 5.1.2 Results and Discussion

A summary of the data collected for each individual replication of the pressure infiltrometer is given in Appendix 5a. along with the calculated hydraulic parameters. A listing of the bulk density, soil water content versus matric flux potential $\psi_m$ measurements, and the calculated pore size distribution (volumetric), for all the undisturbed cores are given in Appendix 5b.

The field saturated hydraulic conductivity values, $K_{fs}$, measured with the GPI are given in Table 51. The arithmetic and geometric mean values were again calculated since $K_{fs}$ generally has a log-normal probability distribution in the field.

As with the 1988 TED study, the GPI values for all three treatment blocks showed considerable variability in measured $K_{fs}$. In Block 1, average

Table 51: Measured $K_{fs}$ from pressure infiltrometer for Elora Research Station

| | | Field saturated hydraulic conductivity ($m \cdot s^{-1} \times 10^{-6}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Replicate | | | | | | | Geometric | | Arithmetic | |
| Block | Mgt/Yr | 1 | 2 | 3 | 4 | 5 | 6 | 7 | $\bar{X}$ | S | $\bar{X}$ | S |
| 1 | MB 20 | 1.48 | 7.19 | 244.1 | 4.45 | 1.102 | - | - | 6.62 | 8.66 | 51.7 | 107.6 |
| | NT 20 | 4.39 | 0.0927 | 52.74 | 41.66 | 41.50 | 43.11 | 1.41 | 8.08 | 11.22 | 26.4 | 23.2 |
| 2 | MB 20 | 28.1 | 2.22 | 6.6 | 284.0 | 22.6 | | | 19.2 | 6.66 | 68.7 | 120.8 |
| | NT 20 | 30.8 | 4.68 | 117.0 | 4.0 | 1.07 | | | 9.37 | 6.37 | 31.5 | 49.3 |
| 3 | MB 20 | 1.19 | 7.39 | 0.074 | 0.593 | - | | | 0.79 | 6.7 | 2.31 | 3.42 |
| | NT 20 | 20.82 | 15.92 | 5.19 | 21.44 | 14.09 | | | 13.9 | 1.8 | 15.5 | 6.56 |

$K_{fs}$ values in the moldboard plots were much higher than those found in the no-till, but with a very high standard deviation. The difference was not found to be statistically significant at the 0.05 probability level.

Additional replicates taken in Blocks 2 and 3 showed the same high variability within each treatment block. In Table 52, the overall average for the moldboard treatment indicated a $K_{fs}$ that was 75% higher than the no-till, which was consistent with the results found at D. Lobb's in 1988. The difference, however, was not significant (0.05 probability) and after twenty years, tillage has not had a very significant effect. These readings were taken, however, after the plots had been idle for one year (18 months since last ploughing), allowing for some consolidation in the plough layer. This could reduce the difference between treatments. The $K_{fs}$ and Ksat values (Table 53) were poorly correlated (r = 0.16).

A summary of the Matric Flux Potential, $\phi_m$ (Table 54) indicated a slightly higher potential for unsaturated flow in the moldboard site, though again this was not significant at the 0.05 probability level.

The differences between treatments can be partially explained by looking at the measured porosity indices from the undisturbed cores (Tables 55, 56, and 57). These data are summarized in Table 58. The no-till treatment had a slight but significant (0.01 probability level) increase in bulk density which was reflected by the decrease in total porosity. The slight difference in $K_{fs}$ and other hydraulic properties can thus be explained by the slight but significant decrease in porosity and macroporosity in the no-till treatment.

Table 52: Summary of average $K_{fs}$ for Elora Research Station

| | | Field Saturated Hydraulic Conductivity Kfs ($m \cdot s^{-1}$ $x10^{-6}$) | |
|---|---|---|---|
| | | MB20 | NT20 |
| Block | Texture | | |
| 1 | L | 51.7 | 26.4 |
| 2 | L | 68.7 | 31.5 |
| 3 | L | 2.31 | 15.5 |
| Overall Average | | 43.6[a] | 24.7[a] |
| S.D. | | 94.1 | 29.4 |

Values with different letters are significantly different at 0.05 probability level.

Table 53: Comparison of Average $K_{fs}$ (from GPI) and $K_{sat}$ (from undisturbed cores) for Elora.

| Block | Tillage | $K_{fs}$ (GPI) ($m \cdot s^{-1}$ $x10^{-6}$) (Y) | $K_{sat}$ (Core) ($m \cdot s^{-1}$ $x10^{-6}$) (X) |
|---|---|---|---|
| 1 | MB20 | 51.7 (107.6) | 1875.1 (2306.8) |
| | NT20 | 26.4 (23.2) | 962.9 (1848.1) |
| 2 | MB20 | 68.7 (120.8) | 93.8 (201.3) |
| | NT20 | 31.5 (49.3) | 95.1 (133.6) |
| 3 | MB20 | 2.31 (3.42) | 41.2 (69.1) |
| | NT20 | 15.5 (6.6) | 17.5 (28.9) |

Correlation of Y on X  r = 0.16

Table 54: Summary of tillage effects on average matric flux potential measurements for Elora Research Station.

| Site | Mgt | Matric Flux Potential ($m^2 \cdot s^{-1}$ x$10^{-6}$) | Initial Soil Water Content ($m^3 \cdot m^{-3}$) |
|---|---|---|---|
| 1 | MB20 | 9.9 | 39.0 |
| | NT20 | 3.35 | 39.6 |
| 2 | MB20 | 3.14 | 37.3 |
| | NT20 | 3.41 | 39.6 |
| 3 | MB20 | 0.12 | 39.8 |
| | NT20 | 0.90 | 39.5 |
| Average | MB20 | 6.52[a] (4.78) | 38.7[a] (1.28) |
| | NT20 | 2.55[a] (1.43) | 39.6[a] (0.06) |

Values in each column with different letters are significantly different at 0.05 probability level.

Table 55: Summary of porosity indices for Elora from undisturbed cores - Block 1.

| Tillage/Rep | | Bulk Density ($g \cdot cm^3$) | Total Porosity ($m^3 \cdot m^{-3}$) | Macroporosity ($m^3 \cdot m^{-3}$) | Relative Macroporosity (%) |
|---|---|---|---|---|---|
| MB20 | 1 | 1.25 | 0.530 | 0.089 | 16.8 |
| | 2 | 1.17 | 0.544 | 0.112 | 20.6 |
| | 3 | 1.23 | 0.551 | 0.086 | 15.6 |
| | 4 | 1.30 | 0.520 | 0.041 | 7.9 |
| | 5 | 1.39 | 0.533 | 0.049 | 9.2 |
| $\bar{X}$ | | 1.27 | 0.533 | 0.075 | 14.0 |
| NT20 | 1 | 1.39 | 0.498 | 0.053 | 10.6 |
| | 2 | 1.32 | 0.499 | 0.053 | 10.6 |
| | 3 | 1.28 | 0.523 | 0.053 | 10.1 |
| | 4 | 1.37 | 0.515 | 0.054 | 10.5 |
| | 5 | 1.44 | 0.477 | 0.023 | 4.8 |
| | 6 | 1.48 | 0.497 | 0.068 | 13.7 |
| | 7 | 1.40 | 0.507 | 0.038 | 7.5 |
| $\bar{X}$ | | 1.38 | 0.502 | 0.049 | 9.7 |

Table 56: Summary of porosity indices for Elora from undisturbed cores - Block 2.

| Tillage/Rep | | Bulk Density ($m^3 \cdot m^{-3}$) | Total Porosity ($m^3 \cdot m^{-3}$) | Macroporosity ($m^3 \cdot m^{-3}$) | Relative Macroporosity (%) |
|---|---|---|---|---|---|
| MB20 | 1 | 1.28 | 0.529 | 0.058 | 11.0 |
| | 2 | 1.28 | 0.513 | 0.075 | 14.6 |
| | 3 | 1.27 | 0.522 | 0.061 | 11.7 |
| | 4 | 1.25 | 0.536 | 0.050 | 9.3 |
| | 5 | 1.25 | 0.552 | 0.083 | 15.0 |
| $\bar{X}$ | | 1.27 | 0.530 | 0.065 | 12.3 |
| NT20 | 1 | 1.32 | 0.545 | 0.055 | 10.1 |
| | 2 | 1.27 | 0.529 | 0.045 | 8.5 |
| | 3 | 1.25 | 0.541 | 0.073 | 13.5 |
| | 4 | 1.39 | 0.508 | 0.046 | 9.0 |
| | 5 | 1.34 | 0.529 | 0.040 | 7.6 |
| $\bar{X}$ | | 1.31 | 0.530 | 0.052 | 9.7 |

Table 57: Summary of porosity indices for Elora from undisturbed cores - Block 3.

| Tillage/Rep | | Bulk Density ($m^3 \cdot m^{-3}$) | Total Porosity ($m^3 \cdot m^{-3}$) | Macroporosity ($m^3 \cdot m^{-3}$) | Relative Macroporosity (%) |
|---|---|---|---|---|---|
| MB20 | 1 | 1.47 | 0.486 | .041 | 8.4 |
| | 2 | 1.42 | 0.508 | .051 | 10.0 |
| | 3 | 1.38 | 0.483 | .025 | 5.2 |
| | 4 | - | - | - | - |
| | 5 | - | - | - | - |
| $\bar{X}$ | | 1.42 | 0.492 | 0.039 | 7.9 |
| NT20 | 1 | 1.28 | 0.515 | .042 | 8.1 |
| | 2 | 1.44 | 0.510 | .042 | 8.2 |
| | 3 | 1.32 | 0.550 | .070 | 12.7 |
| | 4 | - | - | - | - |
| | 5 | - | - | - | - |
| $\bar{X}$ | | 1.35 | 0.525 | .051 | 9.7 |

Table 58: Summary of average treatment effects in porosity indices for Elora Research Station.

| Site | MGT | Bulk Density ($g \cdot cm^3$) | Total Porosity ($m^3 \cdot m^{-3}$) | Macroporosity ($m^3 \cdot m^{-3}$) | Relative Macroporosity (%) |
|---|---|---|---|---|---|
| 1 | MB20 | 1.27 | 0.533 | .075 | 14.0 |
| | NT20 | 1.38 | 0.502 | .049 | 9.7 |
| 2 | MB20 | 1.27 | 0.530 | .065 | 12.3 |
| | NT20 | 1.35 | 0.525 | .052 | 9.7 |
| 3 | MB20 | 1.42 | .492 | .039 | 7.9 |
| | NT20 | 1.35 | .525 | .051 | 9.7 |
| Overall Average | MB | 1.32[a] | 0.518[a] | .06[a] | 11.4[a] |
| | NT | 1.36[b] | 0.517[a] | .05[b] | 9.7[b] |

Values in each column with different levels are significantly different at 0.01 probability level

## 5.2 A. Jones T-2000 Site, Fingal Ontario

### 5.2.1 Site Description

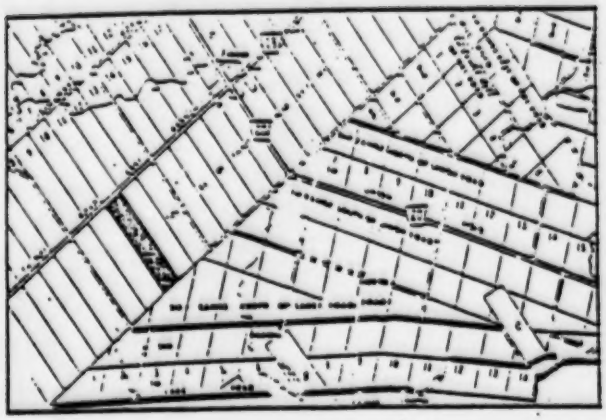
The T-2000 site of Al and Paul Jones is located in Elgin County, Southwold Township, Lot 11, Concession East Branch on the south side of Talbot Road (Figure 9). This site was chosen because four tillage systems have been in place for four years and it has a slightly heavier soil texture (silt loam). The four paired tillage systems include two minimum tillage systems; ridge and soil saver, along with a no-till and moldboard plough treatment. The topography is flat (slope <1-2%) with a Beverly silt loam soil. GPI readings were taken near T-2000 benchmarks 2 and 3, with 4 to 5 replications spaced randomly in each treatment (Figure 10).

### 5.2.2 Results and Discussion

The $K_{fs}$ measurements from the GPI are given in Appendix 6a. The moisture retention curve data from the undisturbed cores are included in Appendix 6b. A summary of the $K_{fs}$ values measured with the pressure infiltrometer are given in Table 59, with corresponding $K_{sat}$ values from undisturbed cores taken immediately adjacent to the GPI reading. Both the geometric and arithmetic means are reported for each treatment.

Each of the four treatments had a high coefficient of variation for both $K_{fs}$ and Ksat, which may be due to both natural variability and the fact that sampling locations were chosen randomly within a corn row without avoiding wheel tracks, cracks, etc. The general trend indicated that moldboard, no-till and ridge till have similar average hydraulic conductivities while the soil saver is much higher by 4-7x. However, because of the high variability, there was not any significant difference between any two treatments at the 0.05 probability level (Table 60).

"FARM LOCATION"



**Al and Paul Jones**
Elgin County
Southwold Township
Lot 11, Concession East Branch
South Side Talbot Road

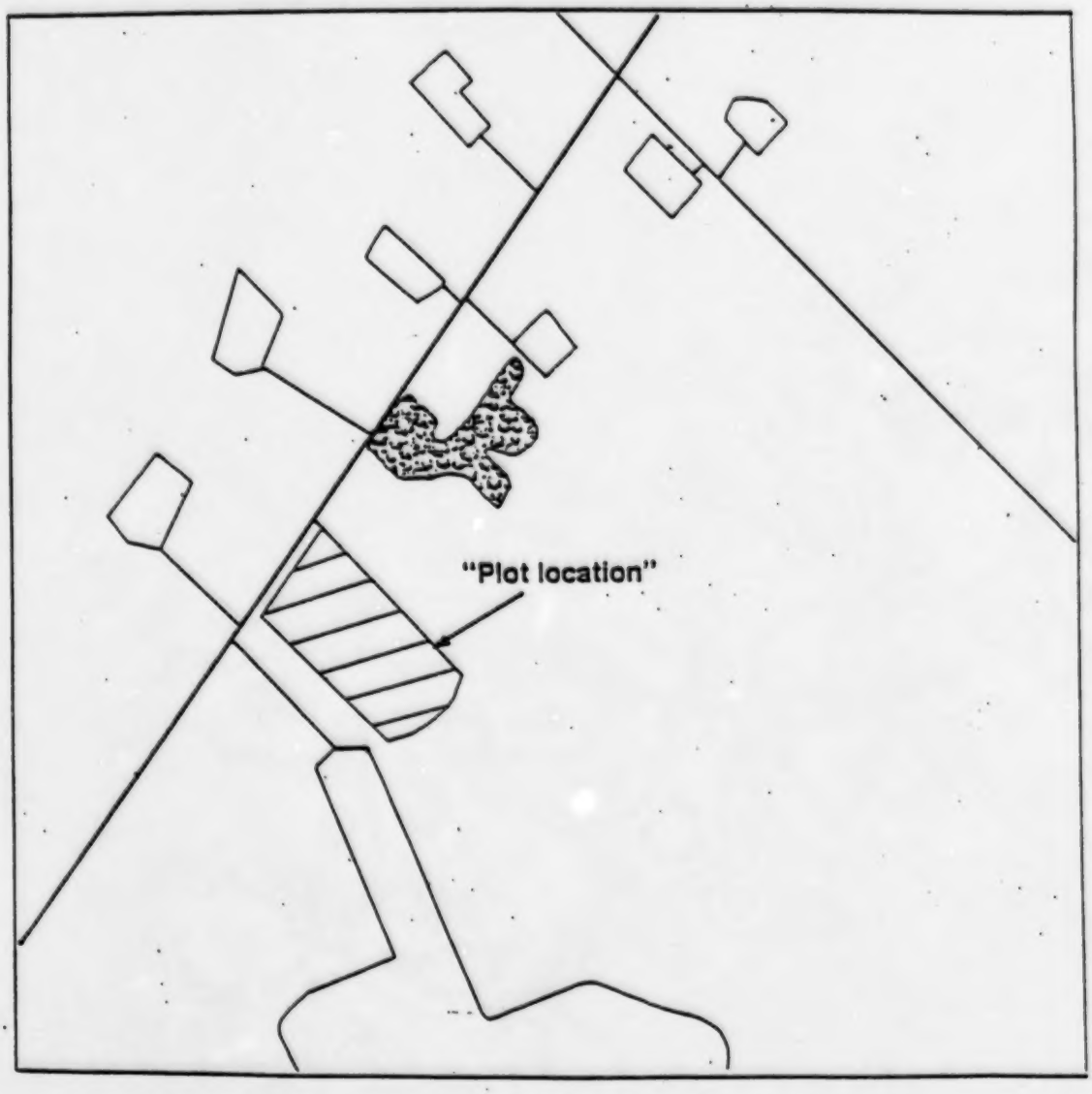



Fig. 9 Site location - A. Jones T-2000 Site, Fingal Ontario

# JONES — Detailed Plot Description

All distances in meters

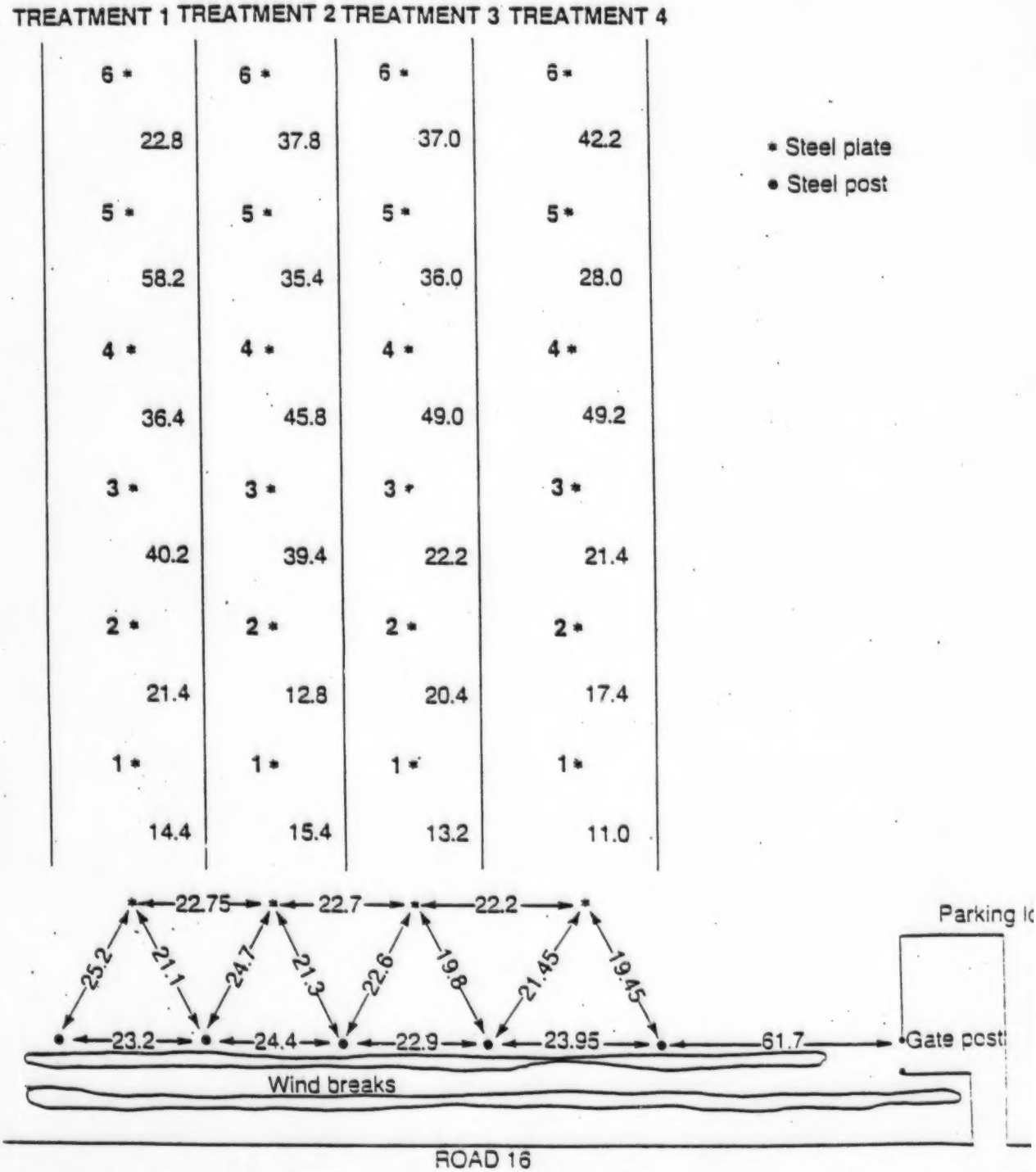



Fig. 10 Detailed plot layout - A. Jones T-2000 Site, Fingal Ontario

Table 59: Measured hydraulic properties from pressure infiltrometer (Kfs) and undisturbed cores (Ksat) for A. Jones (T-2000)

| | | Hydraulic Conductivity ($m \cdot s^{-1} \times 10^{-5}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tillage System | | Replication Number | | | | | Geometric | | Arithmetic | |
| | | 1 | 2 | 3 | 4 | 5 | $\bar{X}$ | S | $\bar{X}$ | S |
| Ridge Till | Kfs | 2.39 | 1.46 | 0.95 | 3.6 | - | 1.86 | 1.79 | 2.101 | 1.16 |
| | Ksat | 0.14 | 27.0 | 0.53 | 2.1 | | 1.42 | 9.55 | 7.43 | 13.1 |
| Soil Saver | Kfs | 40.02 | 0.53 | 6.59 | 12.06 | 35.27 | 9.03 | 5.76 | 18.9 | 17.7 |
| | Ksat | 9.31 | 5.73 | 0.32 | 16.8 | 25.4 | 5.91 | 5.65 | 11.5 | 9.8 |
| No Till | Kfs | 13.01 | 0.009 | 1.84 | 1.32 | 0.98 | 1.0 | 8.7 | 3.44 | 5.4 |
| | Ksat | - | 0.18 | 0.13 | 23.5 | 0.59 | 0.75 | 10.83 | 6.09 | 11.6 |
| Moldboard | Kfs | 0.92 | 0.08 | 11.29 | 9.37 | 0.34 | 1.21 | 8.51 | 4.40 | 5.47 |
| | Ksat | 53.0 | 1.53 | 4.35 | 0.18 | 1.61 | 2.53 | 7.82 | 12.13 | 22.9 |

Table 60. Summary of field saturated hydraulic conductivity $K_{fs}$ for A. Jones, Fingal, Ontario.

| Tillage | $K_{fs}$ ($m \cdot s^{-1} \times 10^{-5}$) |
|---|---|
| Ridge Till | 2.10[a] |
| Soil Saver | 18.9[a] |
| No Till | 3.44[a] |
| Moldboard | 4.40[a] |

Values in the same column with different letters are significantly different at 0.05 probability level

A comparison of the in-situ $K_{fs}$ measurements and the laboratory measured $K_{sat}$ values from undisturbed cores (Table 61) show poor correlation ($r = 0.56$). The $K_{sat}$ values are typically higher than measured $K_{fs}$, except in the soil-save site suggesting that the mean $K_{fs}$ for the soil save site may be artificially high.

The porosity indices, obtained from the individual undisturbed cores, are shown in Table 62 and summarized in Table 63. The results suggest that the no-till had a significantly higher average bulk density and lower total porosity than the other three treatments. This was not reflected in a slightly lower average no-till $K_{sat}$ or $K_{fs}$ value. Two of the replicates in the no-till site were also very high and increased the mean value in the NT twofold Similarly, macroporosity values in the no-till were 2x lower than in the other three, as was the relative macroporosity. The high variability at this site suggests more intensive sampling is required to characterize the surface hydraulic properties at this site. It was difficult to acheive a good data set because of the severe cracking of the soil surface. This caused some surface venting of the permeameter flow, and in some replicates only a single head measurement was possible because of high flow. The radially symmetric 3D flow pattern of the permeameter theory was probably violated under these field conditions.

Table 61: Comparison of Average $K_{fs}$ from pressure infiltrometer vs $K_{sat}$ from undisturbed cores Jones T-2000 ($m \cdot s^{-1}$ $x10^{-5}$)

| Tillage | Pressure Infiltrometer (Y) | Undisturbed Core (X) |
|---|---|---|
| Ridge Till | 2.10 (1.16) | 7.43 (13.1) |
| Soil Saver | 18.9 (17.7) | 11.5 (9.8) |
| No Till | 3.44 (5.4) | 6.09 (11.6) |
| Moldboard | 4.40 (5.47) | 12.1 (22.9) |
| (standard deviation) | | |
| Correlation of Y on X | r = 0.56 | |

Table 62: Summary of porosity indices from undisturbed cores (A. Jones - T2000)

| Tillage | | Bulk Density ($g \cdot cm^3$) | Total Porosity ($m^3 \cdot m^{-3}$) | Macroporosity ($m^3 \cdot m^{-3}$) | Relative Macroporosity (%) |
|---|---|---|---|---|---|
| Ridge Till | 1 | 1.28 | 0.541 | 0.125 | 23.1 |
| | 2 | 1.22 | 0.597 | 0.158 | 26.5 |
| | 3 | 1.46 | 0.505 | 0.095 | 18.8 |
| | 4 | 1.29 | 0.578 | 0.149 | 25.7 |
| | 5 | - | - | - | - |
| | $\bar{X}$ | 1.31 | 0.555 | 0.132 | 23.5 |
| Soil Saver | 1 | 1.35 | 0.564 | 0.186 | 33.0 |
| | 2 | 1.48 | 0.488 | 0.083 | 17.0 |
| | 3 | 1.48 | 0.465 | 0.047 | 10.2 |
| | 4 | 1.30 | 0.518 | 0.165 | 31.8 |
| | 5 | 1.19 | 0.567 | 0.222 | 39.1 |
| | $\bar{X}$ | 1.36 | 0.520 | 0.141 | 26.2 |
| No Till | 1 | - | - | - | - |
| | 2 | 1.53 | 0.463 | 0.059 | 12.7 |
| | 3 | 1.63 | 0.438 | 0.053 | 12.1 |
| | 4 | 1.53 | 0.472 | 0.081 | 17.2 |
| | 5 | 1.58 | 0.413 | 0.035 | 8.5 |
| | $\bar{X}$ | 1.57 | 0.446 | 0.057 | 12.6 |
| Moldboard | 1 | 1.10 | 0.601 | 0.178 | 29.6 |
| | 2 | 1.19 | 0.606 | 0.157 | 25.9 |
| | 3 | 1.15 | 0.593 | 0.156 | 26.3 |
| | 4 | 1.19 | 0.591 | 0.161 | 27.2 |
| | 5 | 1.27 | 0.577 | 0.112 | 19.4 |
| | $\bar{X}$ | 1.18 | 0.594 | 0.153 | 25.7 |

Table 63: Summary of average treatment effects in porosity indices from undisturbed cores - A. Jones (T-2000)

| Tillage | Bulk Density ($g \cdot cm^{-3}$) | Total Porosity ($m^3 \cdot m^{-3}$) | Macroporosity ($m^3 \cdot m^{-3}$) | Relative Macroporosity (%) |
|---|---|---|---|---|
| Ridge Till | $1.31^{a}$ (0.1) | $0.555^{a}$ (0.05) | $.132^{a}$ (0.03) | $23.5^{a}$ (3.3) |
| Soil Saver | $1.36^{a}$ (0.12) | $0.52^{a}$ (0.04) | $.141^{abc}$ (0.07) | $26.2^{ab}$ (12.1) |
| No Till | $1.57^{b}$ (.05) | $0.446^{b}$ (.03) | $.057^{bd}$ (.02) | $12.6^{bc}$ (3.7) |
| Moldboard | $1.18^{c}$ (.06) | $0.594^{a}$ (.24) | $.153^{acd}$ (.02) | $25.7^{ac}$ (4) |

(standard deviation)

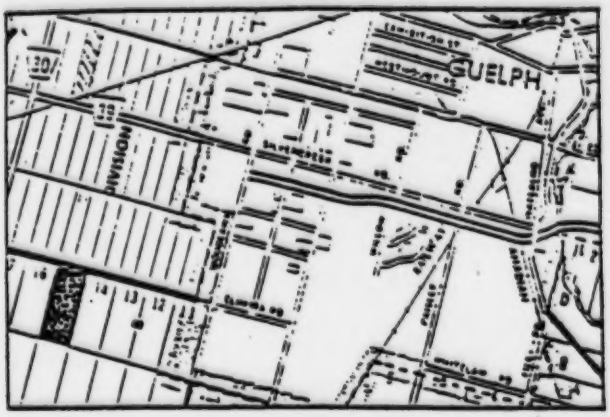
### 5.2.3 Site Description - P. Johnson T-2000 Site, Guelph Ontario

A third site was studied where a minimum versus no-till tillage system has been in place for four years. The farm of Paisley Johnson is located in Wellington County, Guelph Township, Lot 15, Concession 1 (Figure 11). Soil textures range from Guelph Loam to Granby sand. The minimum tillage was a fall soil-saver followed by discing in the spring. Tillage 2000 benchmarks No. 1, 3, 5, and 15 (Figure 12) were sampled on paired sites to determine field saturated hydraulic conductivities over the range of textures and landscape positions found at the site. On average 4-5 replicates were taken at each benchmark, with additional reps taken where high variability was found.

### 5.2.4 Results and Discussion

The raw data from the GPI measurements and the measured porosity indices are given in Appendices 7a. and 7b., respectively. The field saturated $K_{fs}$ values are given in Table 64, along with the geometric and arithmetic means for each tillage treatment. At Benchmark 1, which is located near the crest of a hill, the no-till treatment had an average $K_{fs}$ that was 4x that seen in the minimum till plot, but with a very high coefficient of variation. The next sampling location, Benchmark 3 was located at the mid-slope position. In this case the effect of tillage was reversed, with the minimum till being 4x greater than the no-till. At the lower slope position, the no-till was again higher and on the flat, poorly drained sandy soils at Benchmark 15, the two sites had similar average $K_{fs}$ values. When the overall average for all 18-20 reps was considered, the difference between means was not significant at the 0.05 probability level (Table 64).

"FARM LOCATION"




**Paisley Johnson**
Wellington County
Guelph Township
Lot 15, Concession I Div. B
(519) 822-2248

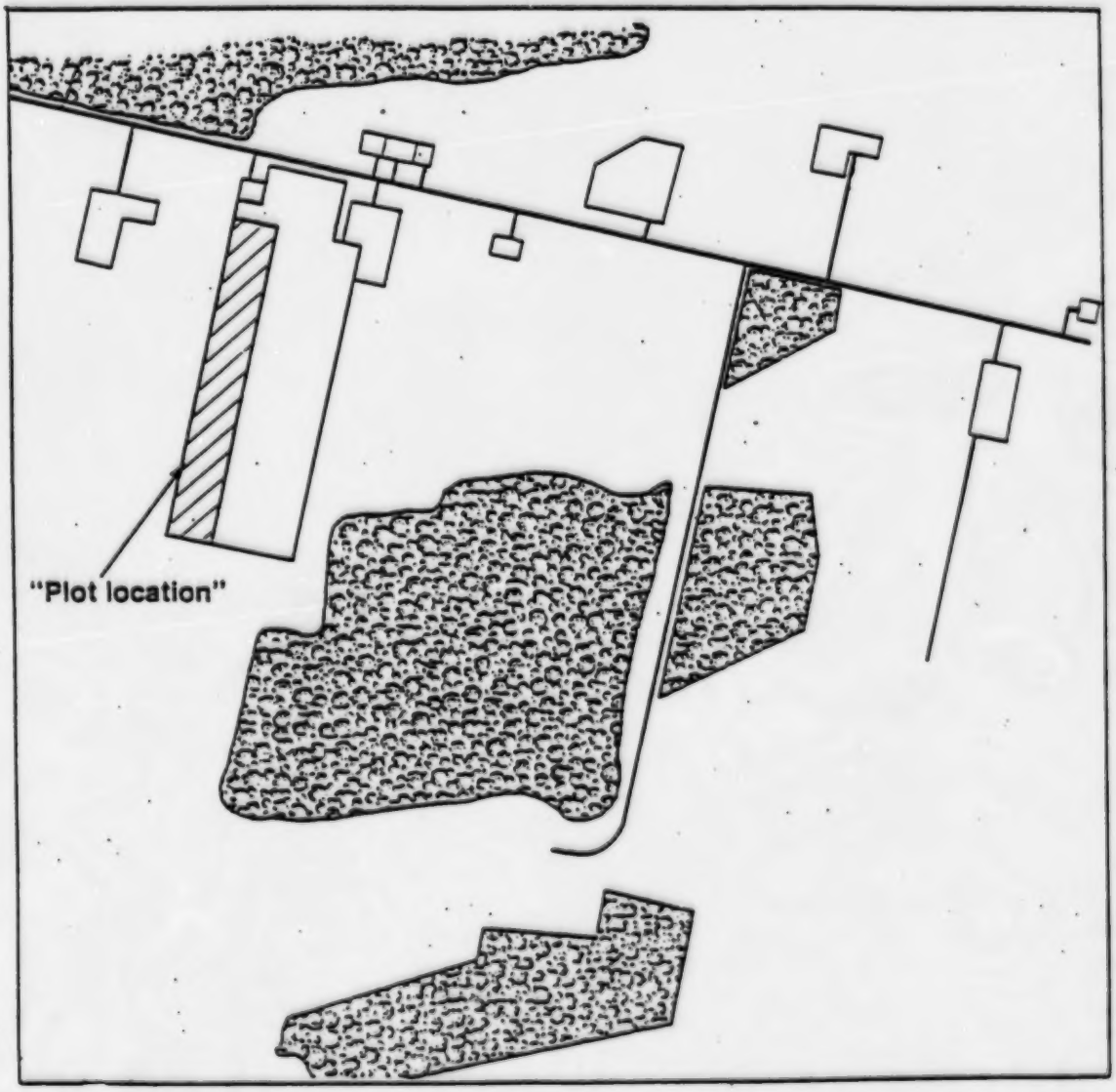



Fig.11 Site location`P.Johnson T-2000 Site, Guelph Ontario

# JOHNSON — Detailed Plot Description

All distances in meters

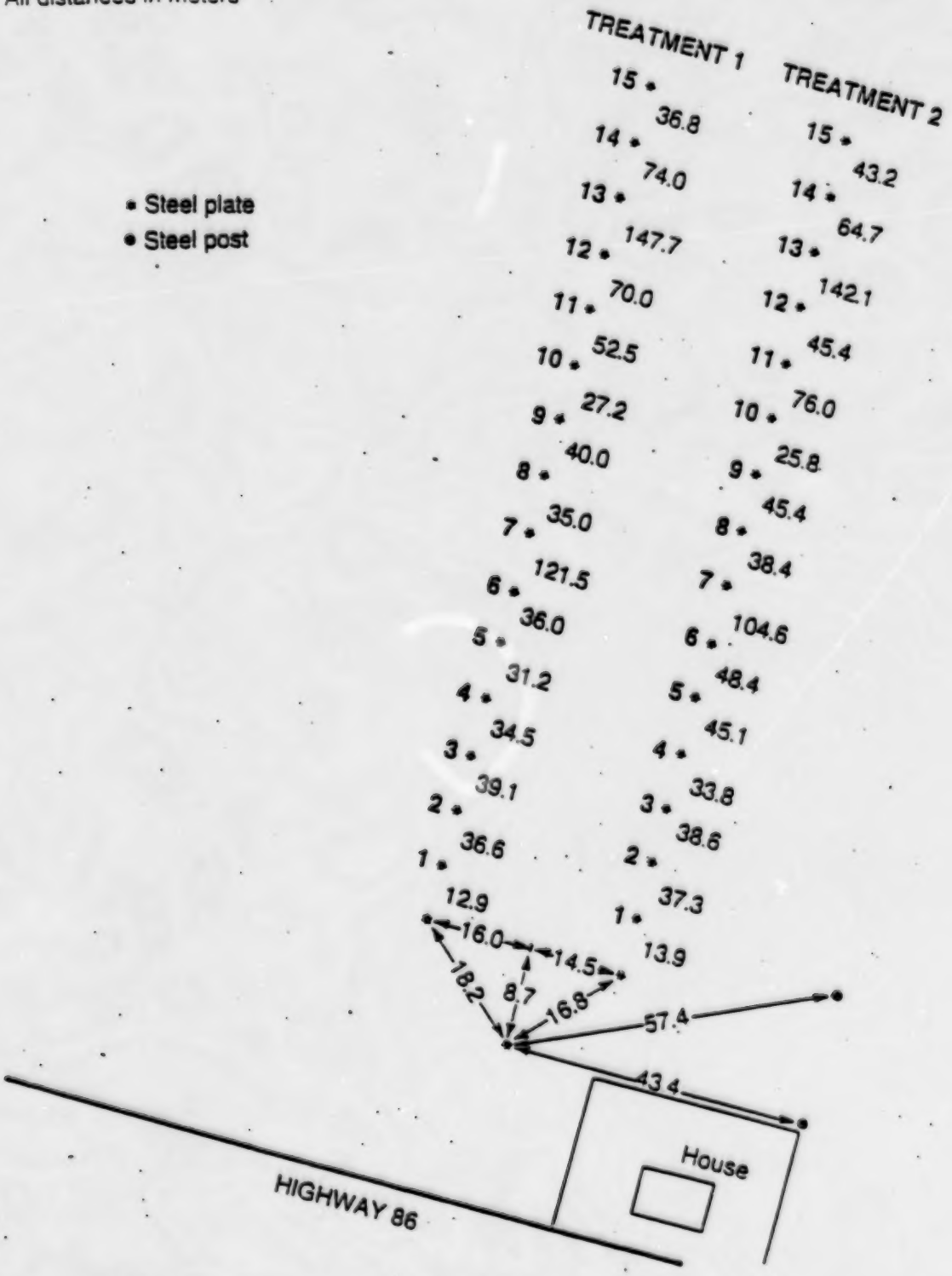



Fig. 12 Detailed plot layout - P. Johnson T-2000 Site

Table 64. Measured $K_{fs}$ from pressure infiltrometer for P. Johnson T-2000 Site

| Site/Tillage | | Field saturated hydraulic conductivity ($m \cdot s^{-1} \times 10^{-6}$) Replication Number | | | | | | | Geometric | | Arithmetic | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | $\bar{X}$ | S | $\bar{X}$ | S |
| 1 | Min | 3.52 | 1.72 | 7.93 | 5.37 | - | | | 4.01 | 1.92 | 4.63 | 2.65 |
| | NT | 0.66 | 3.11 | 82.99 | 15.26 | 1.78 | | | 5.41 | 6.71 | 20.8 | 35.3 |
| 3 | Min | 14.83 | 2.56 | 31.12 | 6.71 | | | | 9.39 | 2.91 | 13.8 | 12.6 |
| | NT | 3.45 | 7.93 | 0.219 | 2.44 | - | | | 1.95 | 4.67 | 3.51 | 3.24 |
| 5 | Min | 3.84 | 0.731 | 1.51 | 51.45 | 5.21 | | | 4.08 | 5.02 | 12.56 | 21.8 |
| | NT | 17.91 | 12.25 | 0.995 | 31.85 | 38.26 | | | 12.16 | 4.35 | 20.2 | 15.0 |
| 15 | Min | 0.742 | 0.914 | 8.3 | 25.54 | 16.48 | 39.81 | 51.26 | 9.01 | 5.69 | 20.43 | 19.5 |
| | NT | 42.87 | 15.87 | 19.6 | 15.05 | 12.04 | | | 18.91 | 1.63 | 21.1 | 12.5 |
| Overall Average | | Min | | 13.98* (16.8) | | | | | | | | |
| | | NT | | 17.08* (20.4) | | | | | | | | |

Values with different letters are significantly different at 0.05 probability level

Table 65: Comparison of $K_{fs}$ with $K_{sat}$ from undisturbed cores for P. Johnson T-2000 site.

| Site/Slope/Tillage | | | Average $K_{fs}$ ($m \cdot s^{-1}$ $x10^{-6}$)(Y) | Undisturbed Core $K_{sat}$ ($m \cdot s^{-1}$ $x10^{-6}$) |
|---|---|---|---|---|
| 1 | Crest | MIN | 4.63 (2.65) | 3.36 (2.19) |
| | | NT | 20.8 (35.3) | 5.29 (7.62) |
| 3 | Mid. | MIN | 13.8 (12.6) | 2.44 (1.94) |
| | | NT | 3.51 (3.24) | 129.6 (183.1) |
| 5 | Lower | MIN | 12.56 (21.8) | 3.04 (2.27) |
| | | NT | 20.20 (15.0) | 3.37 (2.11) |
| 15 | Flat | MIN | 20.4 (19.5) | 296.6 (567.4) |
| | | NT | 21.1 (12.5) | 126.0 (264.4) |
| Average | | MIN | 13.98[a] (16.8) | 105.7[a] (349.7) |
| | | NT | 17.08[a] (20.4) | 62.7[a] (158.7) |

(standard deviation)
Values in each column with different letters are significantly different at 0.05 probability level.
Correlation of Y on X r = 0.20

The matric flux potential, $\phi_m$, and initial soil moisture values (Table 66) revealed very little difference between treatments, with the minimum till having a slightly lower $\phi_m$ and $\theta_v$ than the no-till but the difference was not significant.

The summary of porosity indices from the undisturbed cores (Table 67 and 68) verified that little difference between minimum and no-till existed at this site. The no-till had a slightly higher bulk density on average over all sampled benchmark locations, as well as a lower total porosity. The slightly higher $K_{fs}$ values in the no-till may be related to the higher average macroporosity, though the differences were not significant. The core values are consistent with the GPI measurements.

Table 66: Summary of tillage effects on average matric flux potential $\phi_m$ measurements (P. Johnson).

| Site | Matric Flux Potential ($m^2 \cdot s^{-1} \times 10^{-6}$) | | Initial Soil Water Content (%) | |
|---|---|---|---|---|
| | MIN | NT | MIN | NT |
| 1 | 0.8 | 1.36 | 38.1 | 36.8 |
| 3 | 1.6 | 2.0 | 34.1 | 34.8 |
| 5 | 0.71 | 2.71 | 40.0 | 40.9 |
| 15 | 1.55 | 0.83 | 39.3 | 42.1 |
| Overall Average | 1.24[a] | 1.79[a] | 38.2[a] | 38.9[a] |
| S.D. | 1.46 | 2.33 | 2.55 | 3.50 |

Values for each soil parameter with different letters are significantly different at 0.05 probability level.

Table 67. Calculated porosity indices from undisturbed core measurements (Johnson T-2000)

| Site/Slope/Replication | | Bulk Density ($g \cdot cm^{-3}$) | | Total Porosity ($m^3 \cdot m^{-3}$) | | Macroporosity ($m^3 \cdot m^{-3}$) | | Relative Macroporosity (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | MIN | NT | MIN | NT | MIN | NT | MIN | NT |
| 1 Crest | 1 | 1.45 | 1.51 | 0.474 | 0.453 | 0.045 | 0.340 | 9.5 | 7.5 |
| | 2 | 1.42 | 1.47 | 0.462 | 0.499 | 0.037 | 0.075 | 8.0 | 15.0 |
| | 3 | 1.47 | 1.53 | 0.484 | 0.465 | 0.036 | 0.032 | 7.4 | 6.9 |
| | 4 | 1.39 | 1.52 | 0.490 | 0.465 | 0.048 | 0.029 | 9.8 | 6.2 |
| | 5 | - | 1.52 | - | 0.458 | - | 0.041 | | 8.9 |
| | $\bar{X}$ | 1.43 | 1.51 | 0.477 | 0.468 | 0.041 | 0.042 | 8.7 | 8.9 |
| 3 Mid. | 1 | 1.45 | 1.33 | 0.467 | 0.511 | 0.040 | 0.111 | 8.6 | 21.7 |
| | 2 | 1.57 | 1.50 | 0.445 | 0.455 | 0.046 | 0.032 | 10.3 | 7.0 |
| | 3 | 1.40 | 1.58 | 0.477 | 0.436 | 0.058 | 0.040 | 12.1 | 9.2 |
| | 4 | 1.58 | 1.61 | 0.470 | 0.425 | 0.035 | 0.033 | 7.4 | 7.8 |
| | 5 | - | - | - | - | - | - | | |
| | $\bar{X}$ | 1.5 | 1.51 | 0.465 | 0.457 | 0.045 | 0.034 | 9.6 | 11.4 |
| 5 Lower | 1 | 1.48 | 1.37 | 0.482 | 0.491 | 0.054 | 0.046 | 11.2 | 9.4 |
| | 2 | 1.47 | 1.47 | 0.497 | 0.464 | 0.075 | 0.043 | 15.1 | 9.3 |
| | 3 | 1.46 | 1.57 | 0.485 | 0.540 | 0.036 | 0.050 | 7.4 | 9.2 |
| | 4 | 1.46 | 1.50 | 0.475 | 0.448 | 0.047 | 0.031 | 9.9 | 6.9 |
| | 5 | 1.34 | 1.47 | 0.504 | 0.491 | 0.076 | 0.088 | 15.1 | 17.9 |
| | $\bar{X}$ | 1.44 | 1.48 | 0.489 | 0.487 | 0.058 | 0.060 | 11.7 | 10.5 |
| 15 Flat | 1 | 1.09 | 1.08 | 0.580 | 0.591 | 0.065 | 0.099 | 11.2 | 16.7 |
| | 2 | 0.93 | 1.03 | 0.646 | 0.587 | 0.145 | 0.066 | 28.6 | 11.2 |
| | 3 | 1.04 | 1.08 | 0.644 | 0.632 | 0.116 | 0.130 | 18.0 | 20.6 |
| | 4 | 1.13 | 1.05 | 0.599 | 0.628 | 0.081 | 0.097 | 13.5 | 15.4 |
| | 5 | 1.06 | 1.09 | 0.605 | 0.592 | 0.095 | 0.097 | 15.7 | 16.4 |
| | 6 | 1.08 | - | 0.590 | - | 0.089 | - | 15.1 | - |
| | 7 | 1.10 | - | 0.598 | - | 0.076 | - | 12.7 | - |
| | $\bar{X}$ | 1.06 | 1.07 | 0.609 | 0.606 | 0.095 | 0.098 | 16.4 | 16.1 |

Table 68. Summary of porosity indices from undisturbed cores for P.Johnson T-2000

| Site | Slope Position | Tillage | Bulk Density ($g \cdot cm^{-3}$) | Porosity ($m^3 \cdot m^{-3}$) | Macroporosity ($m^3 \cdot m^{-3}$) | Relative Macroporosity (%) |
|---|---|---|---|---|---|---|
| 1 | Crest | MIN. | 1.43 | 0.477 | 0.081 | 8.7 |
| | | NT | 1.51 | 0.468 | 0.042 | 8.9 |
| 3 | Mid. | MIN | 1.5 | 0.465 | 0.045 | 9.6 |
| | | NT | 1.51 | 0.457 | 0.054 | 11.4 |
| 5 | Lower | MIN | 1.44 | 0.489 | 0.058 | 11.7 |
| | | NT | 1.48 | 0.487 | 0.060 | 10.5 |
| 15 | Top Flat | MIN | 1.06 | 0.609 | 0.095 | 16.4 |
| | | NT | 1.07 | 0.606 | 0.098 | 16.1 |
| | $\bar{X}$ | MIN | 1.32[a] | 0.524[a] | 0.065[a] | 12.25[a] |
| | S | MIN | 0.20 | 0.067 | 0.03 | 5.09 |
| | $\bar{X}$ | NT | 1.38[a] | 0.507[a] | 0.078[a] | 11.7[a] |
| | S | NT | 0.205 | 0.067 | 0.07 | 5.12 |

Values in each column with different letters are significantly different at 0.05 probability level

## 6.0 Summary

The Technology Evaluation and Development (TED) sub-program was developed with a view towards providing information to farmers about soil conservation. However, little information has been given regarding the effects of management options on surface runoff generation and soil loss. Conservation tillage is associated with greater surface crop residue levels, increased infiltration and decreased runoff and erosion as compared to conventional tillage (Baeumer and Bakermans, 1973; Blevins et al. 1983). However, studies have also shown the opposite results with conventional tillage having higher infiltration rates and saturated hydraulic conductivity values, and lower runoff than minimum or zero-till (Lindstrom et al. 1981; Lindstrom and Onstad, 1984). Part of the reason for the conflicting results has been the lack of an easy, field portable method of assessing changes in surface soil hydraulic properties. The Guelph Pressure Infiltrometer (GPI) has proven to be a useful tool for providing accurate field data on saturated and unsaturated flow. It can also be used to estimate the effective time to ponding Tp, which is quite a useful parameter for assessing management effects on potential runoff generation (Kachanoski et al. 1989).

The purpose of the 1989-90 study was to use the GPI to assess the effects of management (i.e. tillage) on surface hydraulic properties. Specific objectives were: to test the relationship between rainfall runoff and predicted runoff using soil parameters measured with the GPI; to examine spatial and temporal changes in soil hydraulic properties; and to characterize the nature of these changes under a range of cropping/tillage systems.

Many of the major conclusions of the 1989-90 study have been given in

the discussion of the measurements at each site but a number of observations can be made. Soil hydraulic parameters such as $K_{fs}$ and $\phi_m$ exhibit high coefficients of spatial variation (both within and between treatments) that are similar to those found in the 1988 TED study. The data are therefore likely representative of the natural variation in the field.

Values for field saturated hydraulic conductivity were generally much higher in the MB versus either MIN or NT treatments. As well, measured $\phi_m$ values were consistently lower in the NT than those found in MB treatments. Estimated time to ponding Tp, calculated from $\phi_m$ and initial volumetric moisture content ($\theta_v$), was considerably shorter in the NT treatments. Intact soil cores, taken at each site, showed that NT resulted in a decrease in total overall porosity and macroporosity, therefore accounting for the decrease in $K_{fs}$ and subsequent lowering of steady state infiltration rates observed at each of the T-2000 rainfall simulation study sites (re: Lobb, Ghent and Anthony). These effects were consistent across all sampling periods and were not dependent on the time of sampling.

Measurements taken at a long-term tillage trial (20 year continuous corn on MB and NT) exhibited only marginal increases in $K_{fs}$ in MB versus NT treatments. While the data were again highly variable, it appears that long term tillage did not have a marked effect on $K_{fs}$.

The GPI proved reliable even on heavy soil textures (eg. A. Jones T-2000 site) yet under extremely dry soil conditions where surface cracking occurs it can be difficult to achieve a good data set without violating the boundary conditions for 3D radial flow in the GPI since the saturated bulb often is vented to the surface. It may be more appropriate to use the Tension Infiltrometer under these conditions. As well, the high variability may suggest the need for increased sampling frequency to properly

characterize the spatial distribution of soil hydraulic parameters.

In general, the data may have important implications for soil management. While soil loss was lower in the NT vs both MIN or MB treatments, it did result in increased surface runoff rates. The data suggest that the primary mechanism for reduction of soil and phosphorus loss in NT systems is the protection of soil surfaces by crop residue. However this implies that movement of non-adsorbing chemicals or soil amendments such as manure are more likely to be transported by runoff under a no-till system. This agrees with the work by Bhatnagar (1977) and suggests future research may be needed to characterize the susceptibility of various soil amendments to movement under runoff conditions.

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I certify that all disclosures of inventions or developments as mentioned in the General or Supplemental Conditions have been made and that there is nothing further to disclose.

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